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Sewage Research

LABORATORY INSTRUCTION IN SEWAGE TREATMENT*

By Gordon M. Fair

Abbott and James Lawrence Professor of Engineering and Gordon McKay Professor of Sanitary Engineering, Graduate School of Engineering, Harvard University, Cambridge, Mass.

To my mind there is at least one way in which students can be brought to grips with the subject of sewage treatment: that is by laboratory experimentation. The traditional textbook course supplemented by instruction in the analysis of water and sewage will not do it. To be effective, however, laboratory work must parallel classroom instruction in the theory of sewage treatment and drafting-room practice in the design of treatment works. By such a combination of studies, the concepts of sewage treatment can be made fundamentally real; freed, as it were, from the sheath of empiricism that so often envelopes them in practice.

The equipment provided in the laboratory can be simple, inexpensive, and compact, and so designed as to isolate the individual, salient forces that are operative in different sewage-treatment processes. The end in view should be to acquaint the student tangibly with the most important scientific principles that underlie the performance of sanitary works. Of such principles there are many; among them: gas exchange, sedimentation, coagulation, filtration, interfacial contact, aerobic and anaerobic decomposition, and disinfection. How some of these may be elucidated in the laboratory will be described in this paper. In order to establish an atmosphere of reality, the equipment and procedures described will be those employed by the author and his associates in their own laboratories. A general view of one of these is shown in Fig. 1. A two-storied framework of steel and wood is seen to occupy its center.

Gas Exchange, or Aeration

The absorption and precipitation of gases are associated with all of the biologically-activated sewage-treatment processes and with the reaeration of receiving waters. Oxygen is taken into solution and gases of decomposition are released. There are three general conditions of gas exchange: (1) droplet aeration as in trickling filters; (2) bubble aeration as in diffused-air tanks of activated-sludge plants; and (3) what, for want of a better name, may be termed surface aeration as in lakes, ponds and streams or in mechanical aeration units (in part).

* Presented at the First Annual Convention of the Sewage Works Federation, Chicago, Ill., Oct. 3, 1940.

The last is, in a sense, a special case of the first and does not require independent laboratory demonstration. Figure 2 shows the type of equipment needed.

For droplet aeration, separatory funnels are attached at various heights to the uprights of the framework illustrated in Fig. 1. Water

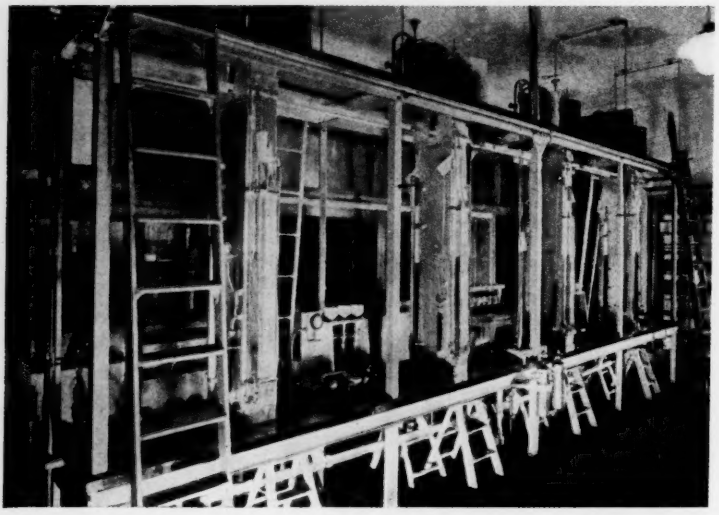

FIG. 1.—General view of one of the laboratories of sanitary engineering at Harvard University.

charged with carbon dioxide or other gases, or deaerated under a vacuum, is dropped from glass nozzles attached to the separatory funnels and is caught, under a layer of mineral oil, in Nessler jars centered below the nozzles. A film of oil rides also on the water surface in the funnels. Unwanted gas exchange is thereby obstructed.

When water that is supersaturated with a gas is aerated, the rate at which the gas is released is proportional to the surface area of the droplet, the time of exposure, and the degree of supersaturation, and inversely proportional to the volume of the droplet. Integration of the resulting differential equation establishes the theoretical equation for droplet aeration and indicates the necessary observational data and the method of analyzing the results. Droplet size is measured by counting the number of droplets discharged by the nozzle into a small graduate. Time of exposure is calculated from the height of fall. Concentration of the dissolved gases before and after aeration is found by chemical analysis. The saturation value of the gas is calculated from tables of physical constants. Results obtained for two nozzles in a typical experiment are shown in Fig. 3.

For bubble aeration, a compressed gas, such as oxygen or carbon dioxide, is bled from a cylinder through a glass nozzle into the bottom of a column of water in a glass standpipe. Here the rate of transfer is proportional to the surface area of the bubbles used, the time of ex-

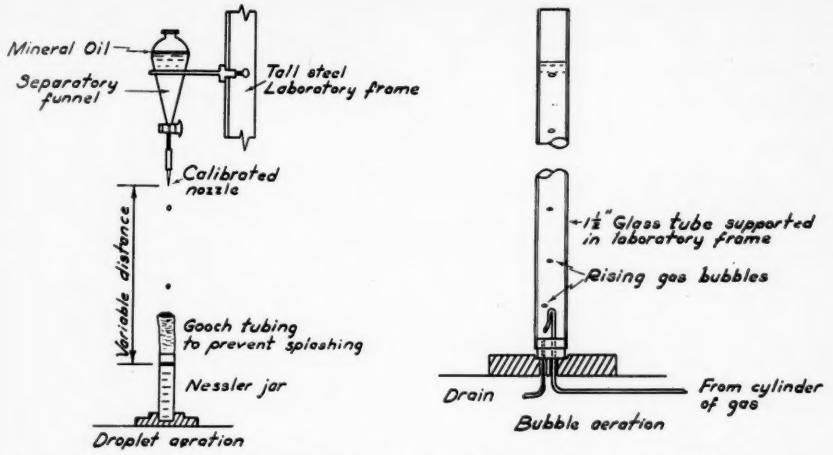

FIG. 2.—Equipment for the measurement of gas exchange by droplet and bubble aeration.

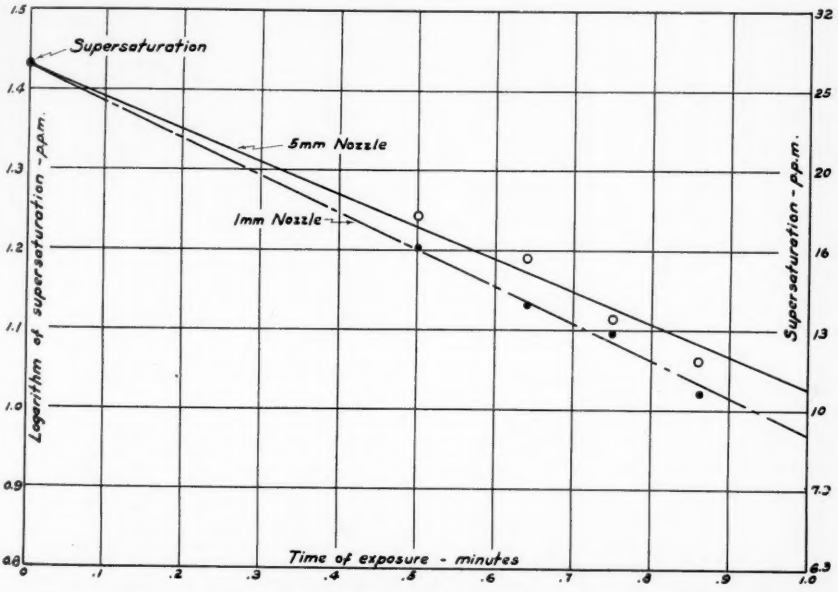

FIG. 3.—Removal of carbon dioxide by droplet aeration. The 5 mm. nozzle liberated a drop 5.5 mm. in diameter; the calculated aeration coefficient is 0.036. The 1 mm. nozzle liberated a drop 4.5 mm. in diameter; the calculated aeration coefficient is 0.035.

posure, and the degree of undersaturation, and inversely proportional to the volume of water. Integration of this differential relationship establishes the theoretical equation for bubble aeration. Size of bubble is measured photographically; time of rise of a single bubble, which is relatively much longer than the time of fall of a droplet, by stopwatch; volume of water by emptying the standpipe into a graduated flask; and

concentration of the gas in the water by chemical analysis. Results for two nozzles in a typical experiment are shown in Fig. 4.

For comparison with the findings of other workers, the aeration coefficients calculated from Figs. 3 and 4 must be converted, if necessary,

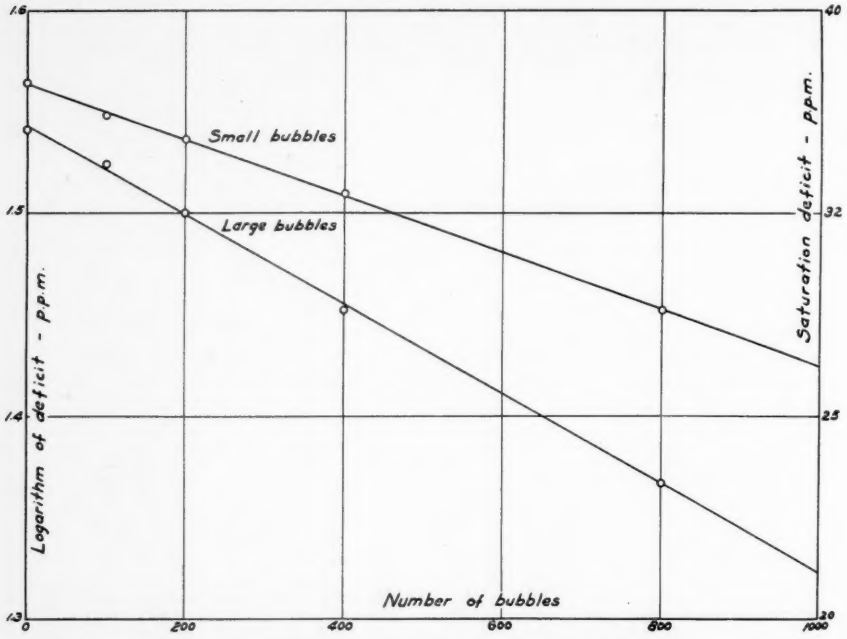

FIG. 4.—Absorption of oxygen by bubble aeration. Size of bubbles was measured photographically; the long (horizontal) diameters were 12 and 9 mm.; the short (vertical) diameters were 6 and 4 mm.; the calculated aeration coefficient is 0.0082 for both lines.

to the Napierian base of logarithms and a unit of time other than seconds. The fundamentally greater effectiveness of droplet aeration is indicated by the relatively greater magnitudes of the aeration coefficients. The overall effect, however, is governed also by the time of exposure and by the expanse of the gas-water interface in its relation to the volume of water. The relatively longer time of exposure to which ascending bubbles can be subjected as against rapid fall of droplets is seen to be an important engineering consideration.

SEDIMENTATION

Although sedimentation occupies a key position in sewage treatment, we are as yet unable to formulate adequately the laws that govern it. Some understanding of sedimentation can be gained, however, experimentally. For the simplest case—the settling of granular matter, as in a grit chamber—we can at least show the validity of Stokes' law and its expansion into the transitional range of sedimentation at higher Reynolds' numbers. Required for this demonstration are a long glass

tube filled with water and a number of substantially uniform grains of quartz sand that are timed as they settle through the water column. The graphical analysis of a single experiment is given in Fig. 5.

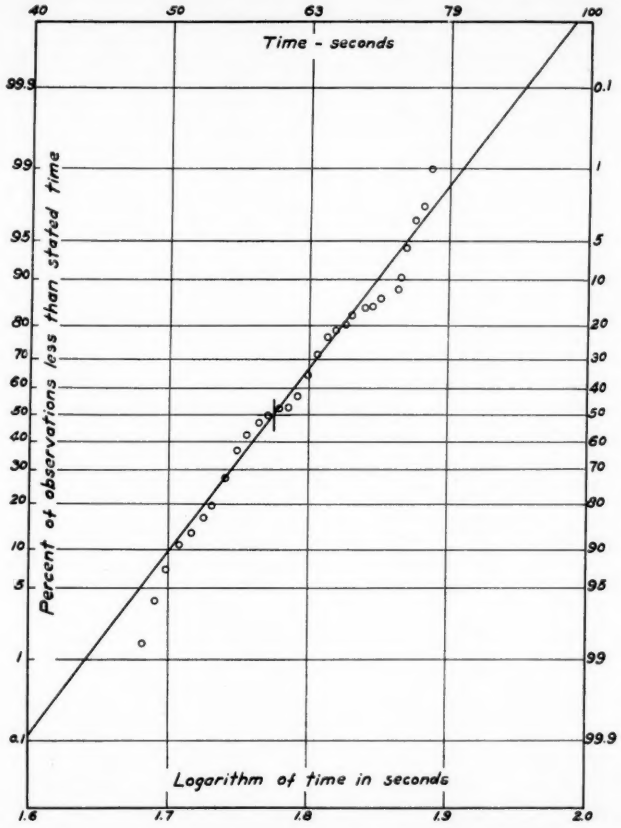

FIG. 5.—Observed time of settling of sand grains. The median value is 59.5 seconds and the geometric standard deviation 1.3. The temperature of the water was 20° C. and the density of the grains 2.65. The grains passed a 60-mesh and were retained on a 65-mesh sieve. The height of settling is 162.5 cm. and the calculated settling velocity 2.73 cm. per second. The calculated equivalent-sphere diameter of the grains is 0.0254 cm.

Weighing and counting the particles gives the equivalent-sphere diameter on the basis of their specific gravity. Particle size lies within or above the range of Stokes' law. The position of the grains referred to in Fig. 5 relative to Stokes' and Allen's values for the rate of settling of spheres in water at 20° C. is recorded in Fig. 6 together with the results of other determinations. Departure from the normal line is due in part to experimental error but largely to the non-spherical shape of the grains. This presents one means for identifying shape, a matter of importance also in connection with filtration, as shown later in this paper.

The settling characteristics of sewage solids are complicated by their variation in size, shape and density and by their tendency to clump together as they settle. While this behavior cannot be measured, it can be demonstrated by visual observation of what happens when sewage is allowed to subside in an Imhoff cone (see Coagulation).

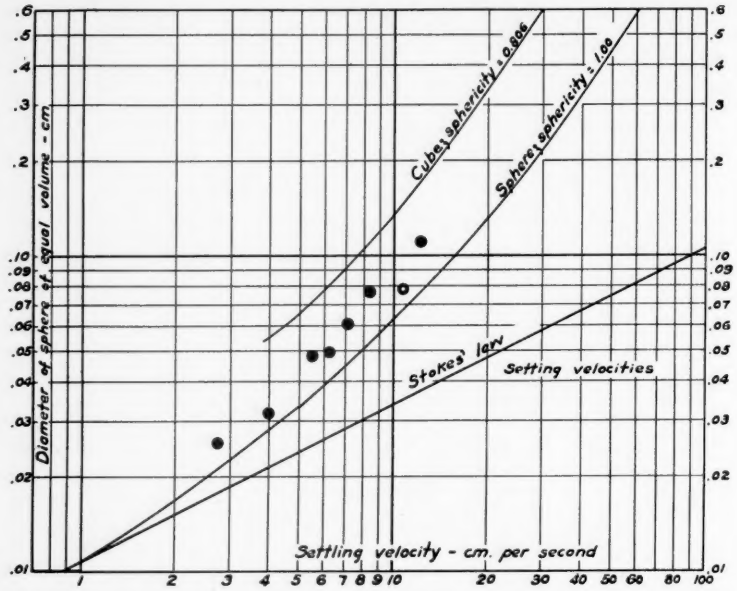
Diameter of sphere of equal volume - cm.
Cubes, sphericity = 0.806
Spheres, sphericity = 1.00
Stokes' law
Setting velocities
Settling velocity - cm. per second

FIG. 6.—Observed settling velocity of sand grains in relation to the laws of Stokes and Allen. The point enclosed in a double circle was obtained with round-grained sand, the remaining points with sharp-grained sands.

An important element in sedimentation is the length of time permitted for the removal of suspended solids. The detention period or quotient of tank capacity and rate of flow is a true measure of time only when there is uniform displacement within the basin. Conditions actually obtaining in a given type of tank may be studied by means of model tests, using dye and salt solutions, for visual observation and conductivity measurements of flow characteristics. If the model is geometrically similar to the prototype, displacement velocity and detention period of the model must be so chosen as to preserve the Froude number that holds for the prototype.

A model settling tank is shown in Fig. 7 together with salt-dosing arrangement and conductivity circuit. To avoid the creation of density currents, the salt solution is heated to make its density equal to that of the water. The results of a single test are recorded in Fig. 8. Determination of the modal and median displacement periods and of the location of the center of gravity as well as further statistical or graphical analysis of the dispersion of the results will tell much about the expected behavior of the tank and its inlet and outlet arrangements. It

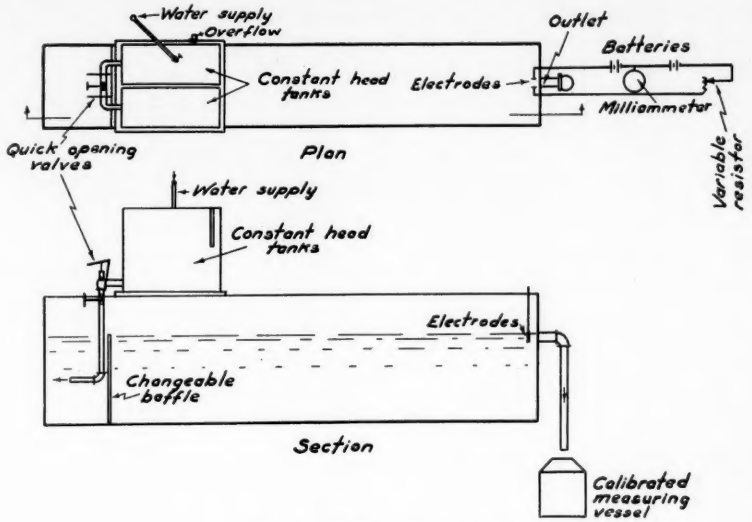

FIG. 7.—Model settling tank.

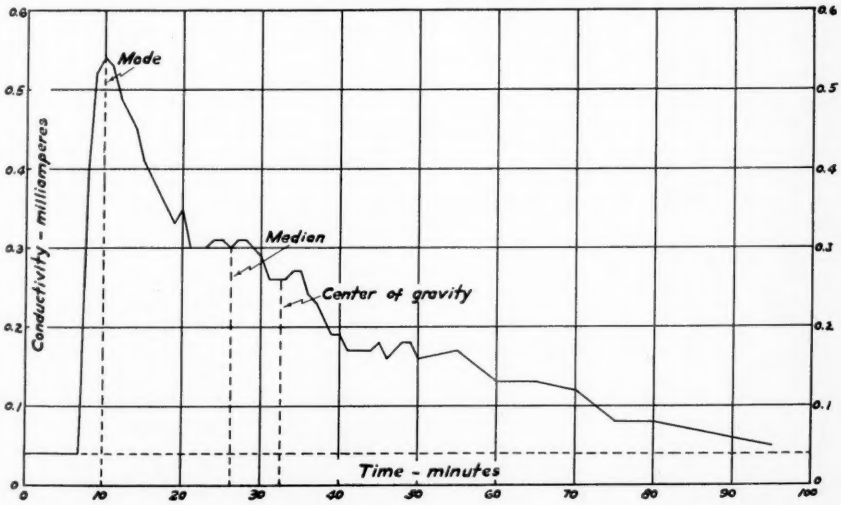

FIG. 8.—Conductivity of effluent of model settling tank. For a scale ratio of 5 the observed detention periods in the model correspond to 21 (modal), 58 (median), and 72 minutes (center of gravity) in the prototype.

must be realized, however, that flow studies such as this do not necessarily give a true picture of settling efficiencies.

COAGULATION

Flocculation of dispersed solids and, to a smaller extent, the precipitation of dissolved substances which occur in connection with the

clarification of sewage by chemical coagulation and in the conditioning of sludge for filtration can be studied in the laboratory by means of stirring motors, Imhoff cones, and Buechner funnels.

In the chemical precipitation of sewage, observation of floc formation is aided by projecting a Tyndall beam through the liquid. A battery of stirrers mounted upon a steel box which contains an automobile head lamp and a bulls eye lens for each stirrer is shown in Fig. 9. Floc

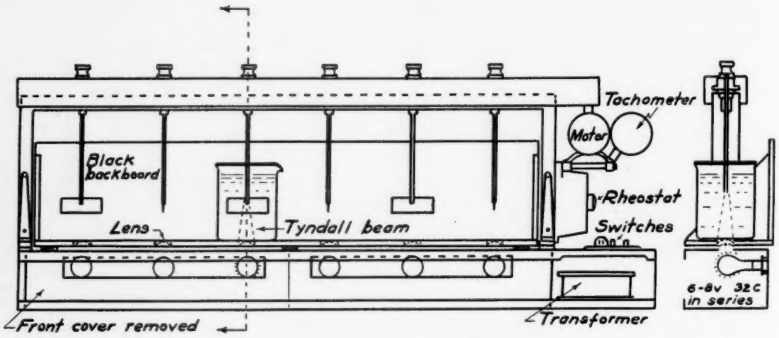

FIG. 9.—Stirring device. Tyndall beam facilitates observation of floc formation.

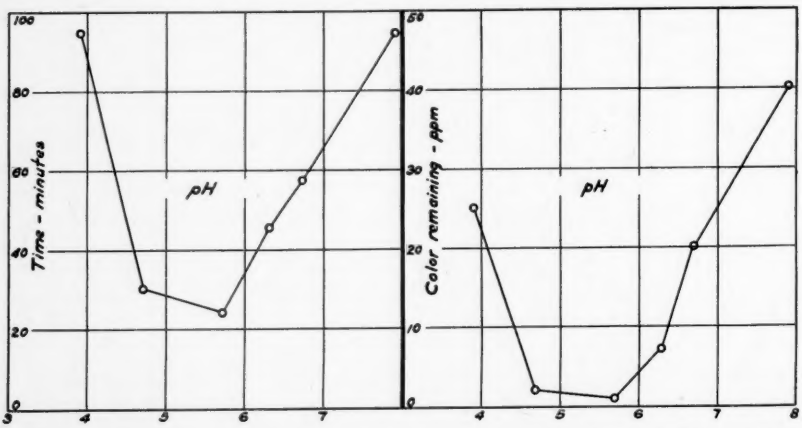

FIG. 10.—Color removal and floc formation when a constant amount of alum is added to river water the pH of which is varied. The color of the sample was 40 p.p.m. and the dosage 1.4 grains per gallon. Control at a pH of about 5.3 is indicated.

formation is viewed against a black background and timed. The stirrers are driven by a variable-speed motor. A revolution counter and rheostat give speed control and make it possible to assign numerical values to the degree of mixing. To study the effect of flocculation, with and without the aid of chemicals, upon the settling characteristics of the sewage, the flocculated sewage is then transferred to Imhoff cones. An example of student observation of floc formation is given in Fig. 10 for an alum-treated river water. This is a satisfactory example of what is called pH control.

To study the effect of elutriation, heating, chemical conditioning, or mechanical thickening upon the dewatering characteristics of sewage sludge, the sludge is removed from the stirring equipment to Buechner funnels, and the amount of sludge liquor collected in given intervals of time by vacuum filtration through filter paper is then measured in 100-ml. graduates. The necessary equipment is shown in Fig. 11, and typical results are presented in Fig. 12.

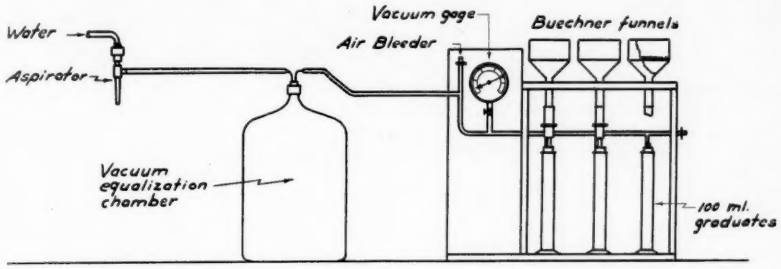

FIG. 11.—Equipment for the vacuum filtration of sludge.

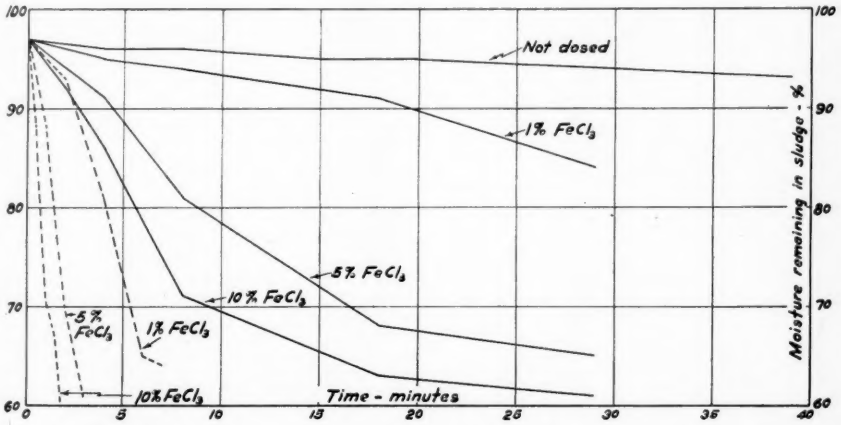

FIG. 12.—Rate of dewatering of sewage sludge after chemical conditioning and elutriation. Solid lines are for unelutriated, dashed lines for elutriated solids. The temperature was 10° C. and the vacuum 10 in. of mercury.

FILTRATION

The continuous passage of sewage through beds of granular material in such manner that the sewage fills the voids of the bed is confined at present to rapid filters of sand or magnetite. Intermittent passage obtains in intermittent sand filters. Among the matters that need consideration in this connection are the description of filtering materials and the laws of flow that govern filtration of the sewage and the washing or cleansing of the bed.

Description of filter grains is based upon a statistical analysis of the results of a sieve separation. Average or characteristic size (geometric mean or Hazen's effective size) and variation in size (standard geometric deviation or Hazen's uniformity coefficient) are found. In addition the sieves must be calibrated. Grain shape is observed under

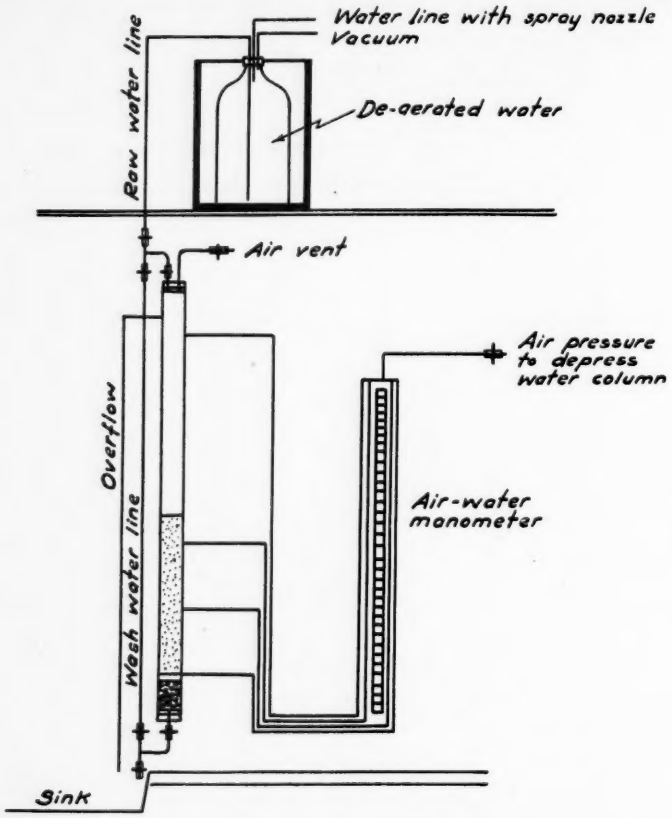

FIG. 13.—Sand filter supplied with deaerated water.

the microscope and may be measured approximately by determining the settling velocity of a representative number of particles as described under Sedimentation. All of these activities make for a better understanding of the physical characteristics of filtering materials. The methods employed are well established and will not be described here.

To study the hydraulic behavior of sand or magnetite beds, glass tubes and suitable gages are provided (Fig. 13). Deaerated water must generally be used in laboratory studies of this kind. Otherwise the release of air within the voids of the filter will interfere seriously with flow. As shown in Fig. 13, water may be deaerated by spraying it

into a carboy that is held under a vacuum. The results of a few filtration and backwashing tests are illustrated in Figs. 14 and 15. These data make it possible to test the validity of Hazen's classical formulation of the flow of water through sand as well as the equations suggested by other workers.

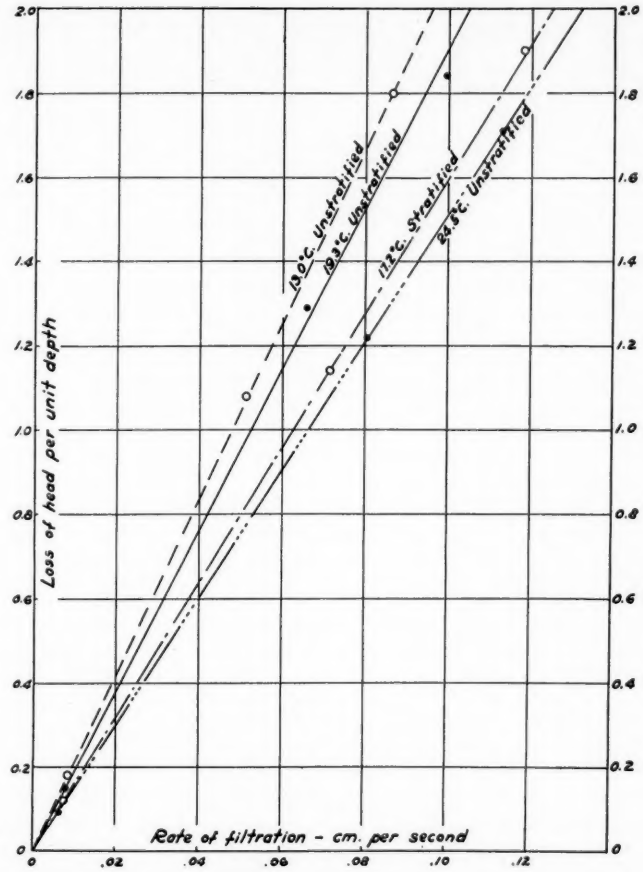

FIG. 14.—Frictional resistance of sand bed. The effective size of sand was 0.21 mm., the uniformity coefficient 1.22, and the percentage of voids 44.4.

INTERFACIAL CONTACT

The removal of suspended, colloidal and dissolved substances by the biological or active slimes of contact beds, trickling filters, contact aerators and activated-sludge tanks is a very complex phenomenon. Much can be learned, however, about the conditions that affect its workings by carrying the problems of interfacial contact into the laboratory. The most useful equipment so far devised for this purpose is some form

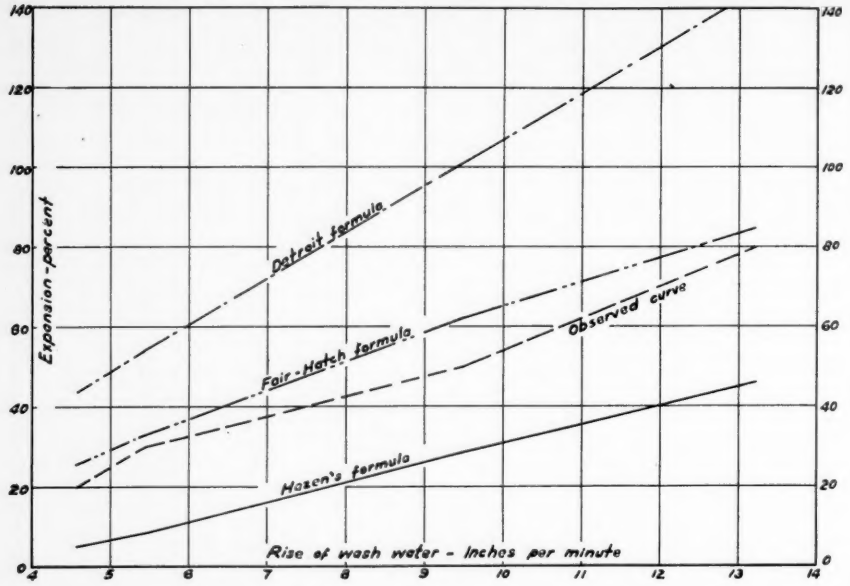

FIG. 15.—Expansion of sand bed. The effective size of sand was 0.21 mm., the uniformity coefficient 1.22 and the temperature 19.2° C.

of respirometer. One such unit is shown diagrammatically in Fig. 16. The apparatus establishes a closed circuit in which the included air is bubbled through the sewage and the slime or contact material. Carbon dioxide is absorbed in a caustic trap and titrated chemically or electrometrically. Oxygen utilization is measured in terms of the contraction in the volume of the included atmosphere. From time to time the oxygen supply is replenished from a cylinder of this gas.

To study the activated-sludge process, for example, sewage is mixed with returned sludge and aerated for the desired length of time. In the course of the experiment, the rates of biochemical oxygen-demand and production of carbon dioxide are determined, and the resulting respiratory quotients are calculated at the end of the test. The mixed liquor is allowed to settle, and changes in constituents as well as other important characteristics are established. Purification efficiencies and the sludge index are computed. The sludge is examined under the microscope, and the living organisms (other than bacteria) that it contains are identified and their relative prevalence estimated. The changes in rate of B.O.D. observed in typical tests are shown in Fig. 17.

ANAEROBIC DECOMPOSITION

The digestion of sewage solids in Imhoff tanks and separate sludge-digestion tanks is a broad and important subject in which many factors influence the efficiency and economy of treatment works. Some of these

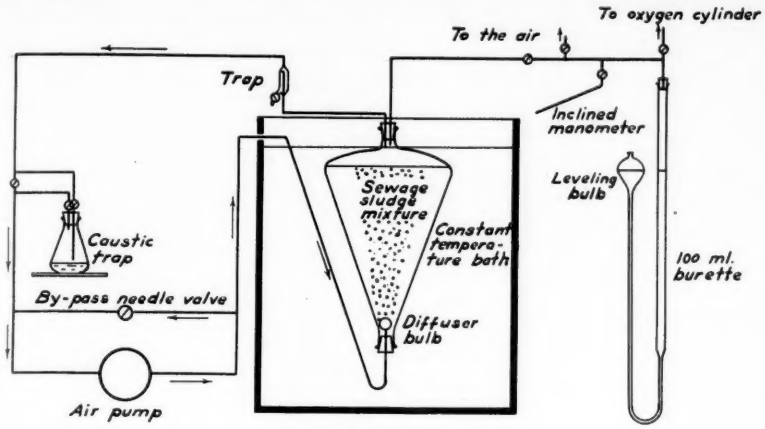

FIG. 16.—Respirometer.

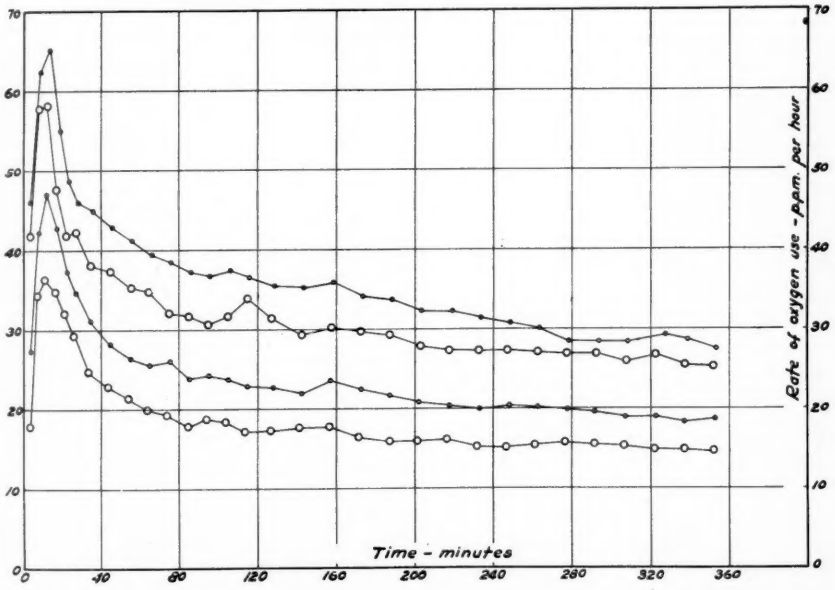

FIG. 17.—Rate of oxygen used by activated sludge. Progressing from top to bottom curves, the content of suspended solids was 2410, 1950, 1520 and 1140 p.p.m., approximately 83 per cent being volatile.

can be investigated on a laboratory scale in such a way that the student will become familiar with the digestion, gas production, and gas utilization aspects of the problem. Suitable apparatus is shown in Fig. 18. It consists of a constant-temperature bath, a weighted glass bottle holding the sludge to be studied and a calibrated gasometer in which a saturated salt solution is displaced by the gases of decomposition.

The course of digestion is followed most readily by measuring the volume of gas evolved and analyzing it for carbon dioxide, oxygen and combustible gas (largely methane). Measurements of hydrogen-ion

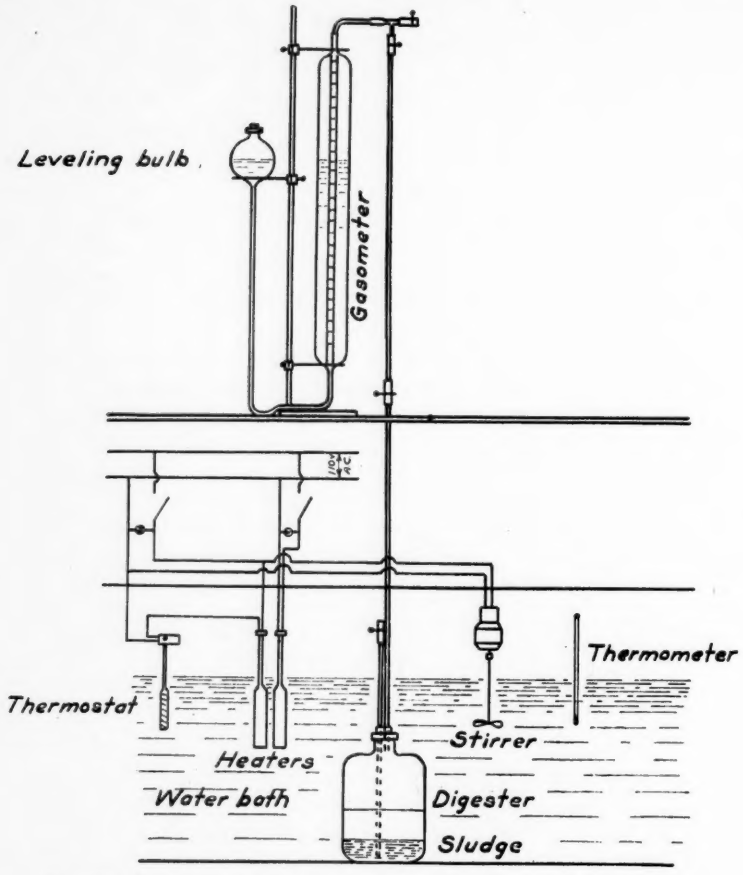

FIG. 18.—Equipment for the measurement of the rate of sludge digestion.

concentration, volatile solids, and similar observations may be carried out on samples withdrawn from the sludge bottle. Changes in the composition of the sludge, however, are determined better by using a series of smaller trapped containers, the total contents of which are analyzed after various stages of digestion have been completed. Among the factors that can be studied are the effects of temperature, seeding, chemical pH control, and source of sludge. The results of student experimentation are shown in Fig. 19. Effects of seeding and temperature are evident.

Other Experiments

Only those experiments have been described in some detail that require laboratory equipment other than that normally needed in the analysis of water and sewage. There are additional worthwhile ex-

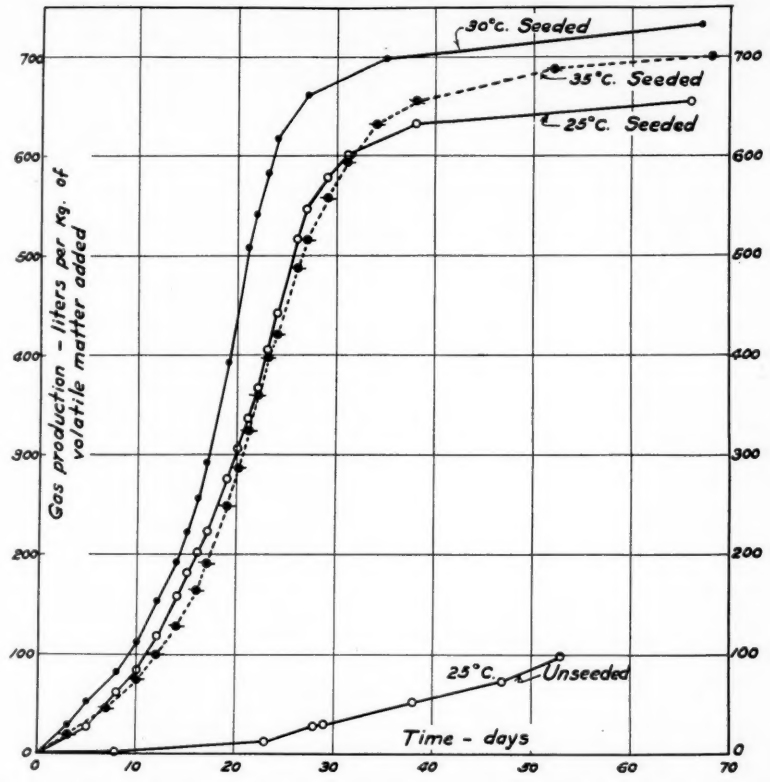

Fig. 19.—Gas production by seeded and unseeded sewage sludge at different temperatures.

periments; among them measurement of long-time biochemical oxygen demand at different temperatures and formulation of the results in terms of a unimolecular reaction; and studies of chlorination—chlorine demand, chlorine residual, and break-point—and development of the die-away curve of bacteria to demonstrate the time-concentration relationship of disinfection.

Conclusion

Experiments such as these will repay the student of sewage treatment in fullest measure for the time and energy expended in their performance. In order to explore the greatest possible number of factors that are of importance in individual experiments, the assignments of

different students or groups of students can be varied to advantage, especially if the results are pooled.

Perhaps it is not too much to hope that properly conceived laboratory exercises in sewage treatment will establish incentives for investigation and habits of scientific attack that will be followed in practice to a larger degree than at present. If so, the profession and the public will benefit by the progress in the science and the art of sewage treatment that is certain to ensue.

The equipment and experimental methods described in this paper were actively developed, in large measure, by the author's colleagues, Professors M. C. Whipple and Edward W. Moore and Messrs. David C. Wiggin, Robert Mitchell and Jack E. McKee. Inspiration for equipment and methods was drawn from many sources. New ways and means of demonstrating principles are constantly being devised.

DISCUSSION OF PROF. FAIR'S PAPER

By Harold E. Babbitt

Professor of Sanitary Engineering, University of Illinois

Professor Fair's paper is both practical and academic. To an instructor in the field of sewage treatment the information in his paper will be found valuable. The information is presented in such a manner as to be both understandable and useful to the adequately-educated, self-instructing sewage treatment plant operator who may wish to duplicate the apparatus and repeat the experiments. It is evident that the tests, to be properly understood, must be made by one having basic training in mathematics, physics, chemistry, and the technique required in the manipulation of precise laboratory apparatus. It is evident that to follow the procedures outlined the experimenter must be familiar with the jargon of the art of sewage treatment since the paper includes such items as:

Nessler jars	Tyndall beam
Buechner funnels	Reynolds number
Stokes law	Napierian logarithm
Integration	Differential equation
Froude number	Modal and median displacement

The advocate of such laboratory instruction must defend the time and expense required for it from the student and by the educational institution. A recent popular, pseudo-scientific article emphasized the difficulty of finding a real expert in the art of television because of the breadth of knowledge required, from histrionics through chemical ions, physical electrons, protons, to and through its possible effect on morons. The *true* expert in the art of sewage treatment also requires broad knowledge. He should know something of the humanities, economics, finances, structural analysis, architecture, landscaping, chemistry, biological sciences, physics, mathematics, French and German

and he should have had a basic cultural education. He must be at once, an engineer, a scientist, a philosopher, and a handy man.

The time required in such intensive laboratory instruction as described in Professor Fair's paper must be taken from the time available for the accumulation of knowledge required in the art of sewage treatment. An educational institution of the highest grade, such as Harvard University, does not aim to develop solely a laboratory technician. The aim is possibly to develop a rounded scientist, specializing in the field of sanitation and the disposal of liquid wastes. The embryo scientist comes to Professor Fair, possibly with a bachelor's degree earned in science or engineering. The knowledge acquired in earning his bachelor's degree supplemented only by the excellent course of "Laboratory Instruction in Sewage Treatment," described by Professor Fair, is less than the broader education necessary to produce an expert in sewage treatment. What then should be added to the instruction? Just as soon as we begin to answer this question the required subjects pile up so rapidly that the time required for the Laboratory Instruction may be greater than can be afforded. From the viewpoint of the enthusiast in sewage treatment I believe that such a course is justified for the purpose indicated. Professor Fair probably agrees with me or he would not be conducting the course. But with what arguments did he convince his Dean, in order to secure the necessary funds? With what arguments or how does he convince his students that the course is worth while in order to persuade them to pursue it with him? Without funds there is no course. Without students there is no instruction.

Justification of the course for postgraduate instruction can be based upon the fact that the work involved makes possible a combined manual, visual, and mental application of the basic scientific principles acquired from texts and lectures to which the student has been exposed in his preparatory training. The course can be justified on the same grounds as are used for demonstrating the value of any laboratory or shop instruction. The most stiff-necked, reactionary academician may advocate that education and culture can best be acquired through reading and listening. But the man educated in the field of sewage treatment must be both academic and practical. He must be able to apply his knowledge; and this laboratory course of Professor Fair's seems to accomplish the desired purpose. It would seem that this Federation of Sewage Works Associations might well encourage the inclusion of such a course in the education of sewerage works men and, to make his paper even more effective the Federation, when and if its organization and effectiveness are expanded, as well as its constituent organizations might adopt resolutions to that effect.

Now turning to the sewage treatment plant operator who has not the opportunity to take such a course of instruction. Can he teach the course to himself? Provided he has had the necessary basic training the answer is yes, because Professor Fair has described the apparatus and procedure with sufficient detail and clarity to permit their duplica-

tion. One additional obstacle confronts the ambitious learner, however, and that is the securing of funds and facilities from his governing body. It should be possible, after studying Professor Fair's paper, to demonstrate that the apparatus and procedure required in most of the experiments can be converted into routine control tests which will make possible the more economical operation of the treatment plant together with the production of a more desirable effluent. From the viewpoint of hard cash the money invested in the apparatus might be many times repaid by reduced operating costs and extended plant capacity.

In some educational institutions which offer instruction in sanitary engineering the problems of administration of the curriculum are sometimes difficult of solution. The subjects to be pursued may be grouped among such classifications as humanities, mathematics, language, drawing, physics, chemistry, engineering, etc., etc. Into which group will this Laboratory Course fall? The chemistry department will claim the course because it involves chemistry; the physicists will want it because of the physical measurements involved; and the engineers will want it because it is all engineering. From a broad viewpoint this conflict of claims may seem trivial but from the practical difficulties met in large educational institutions, to which such instruction is necessarily limited, the difficulties present themselves all too frequently. This conflict of interests was well illustrated by an objection once raised by the Department of Economics in a large University, to the teaching of a course entitled "Economics of Concrete Beams," by the Civil Engineering Department. The head of the latter department pointed out the ridiculousness of the situation by replying that if the Department of Economics were justified in teaching "The Economics of Concrete Beams" on the basis that any subject involving the word economics belonged to the economics department, then since the subject of foundations was distinctly within the field of civil engineering, he would insist that the civil engineering department, and not the department of philosophy, should teach "The Foundations of Christianity."

The reduction to the ridiculous of any proposition sometimes aids to prove its truth. In receiving Professor Fair's paper it seems convincing that: (*a*) the description of apparatus and procedure made by the author gives valuable information to the instructor in the subject of sewage treatment, (*b*) the offering of the instruction is justified by the end attained, (*c*) the instructional value of the work justifies the time devoted to it and (*d*) the administration of the course should be located in that academic department which best combines knowledge of the sciences involved and the practical applications of this knowledge to sewage treatment.

Finally, this organization might now grasp the opportunity to be effective in influencing the trend of education of its recruits and in encouraging their instructors by adopting resolutions and directing their officers to make Professor Fair's paper effective in education for sewage treatment.

CHEMICAL TREATMENT OF SEWAGE*

By Willem Rudolfs

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A little over ten years ago the first laboratory and plant experimental results with small quantities of chemicals (from 1 to 15 p.p.m. ferric chloride) were published. This marked the beginning of modern chemical treatment.[1] These experiments, begun in 1925, were primarily designed to find ways and means to aid existing biological treatment plants and allow units to carry a greater load without extensive new construction. Modern chemical treatment was greatly stimulated with the construction and operation of the Dearborn, Michigan plant in 1932. The plant attracted wide attention on account of its compact and highly mechanized design, and also because of the mechanical method of sludge disposal. Several chemical concerns became interested, seeing an outlet for certain chemicals. Within the next two to three years many claims were made for chemical treatment, a number of which are now happily forgotten. Nevertheless, chemical treatment made rapid progress. Considerable fundamental work has been done and we have now a somewhat better understanding of the principles involved as well as the place chemical coagulation can occupy in modern sewage treatment, although a number of questions remain to be answered.

Chemicals Used

The principal chemicals used at present are alum, lime, ferric chloride, ferric sulfate and chlorinated copperas. These chemicals may be used alone, in combination, or in conjunction with air, chlorine or a biological floc.

Alum, on account of its cost and ease of handling, has been favored in a number of places. The use of alum has some drawbacks which are not always fully realized. As examples we may cite that alum coagulated fresh solids present considerable difficulty in dewatering. The cake is frequently thin, resulting in low yields, and is rather slimy, causing cloth binding and requiring more frequent washing. When alum coagulated solids are digested the rate of digestion is not impaired but the sludge does not compact well, resulting in a thin, fluffy sludge, which requires a greater digestion capacity. Alum coagulated sludge behaves more nearly like activated sludge in a digester than raw fresh solids. The volume of sludge is considerably greater with alum than with ferric chloride and lime. Sludge settles more slowly and is more easily lost over the weirs.

Experiments and plant scale trials seem to indicate that the effect of small quantities of lime on coagulation is perhaps under-estimated.

* Presented at the First Annual Convention of the Sewage Works Federation, Chicago, Ill., Oct. 3, 1940.

For instance, it has recently been found that those substances in sewage responsible for most of the iron demand might be easily removed by lime. These same substances appear to be responsible for the lack of compacting of sludge or cause considerable expansion of the sludge when coagulated by iron salts. The function of lime as an aid to coagulation, by acting as a buffer or pH regulator, is well recognized, but the possibility that under certain conditions a somewhat increased amount of lime applied alone produces equal or better results than a combination of iron salt and lime is of interest. The type of lime appears to be of considerable importance. As a rule high magnesium lime is inferior to high calcium lime.

The use of ferric chloride or ferric sulfate alone or together with lime or chlorine appears to depend upon the character of the sewage and to a less extent upon the cost of the chemicals. In some cases no settleable floc can be obtained with large amounts of ferric sulfate, chlorinated copperas or ferric chloride, but the addition of some lime produces a rapidly settling floc. With some sewages, especially where certain types of soluble organic nitrogenous wastes, textile, and fermentation wastes are present, chlorinated copperas or ferric chloride alone is rather ineffective with the usual smaller quantities employed. Dosages up to 150 p.p.m. iron salt as Fe may fail to cause coagulation.

The use of air as an aid to coagulation is well recognized. The New Britain, Connecticut, plant uses it as routine practice in conjunction with chemicals. A recent inspection showed that the process was producing good results.

During the last several years chemical treatment has been more stabilized and some of the wild claims made a few years ago have been reduced to proper proportions. Nevertheless, chemicals are now used for all year around treatment, seasonal treatment and as adjuncts to biological and physical processes. An interesting development has been the equipment for chemical handling which has been made more flexible, allowing for a choice of chemicals. This is of especial importance when chemical treatment is used throughout the year. The type of treatment may vary in accordance with the variation in sewage and its response to certain chemicals.

Results and Costs

Sufficient information has become available to show that in general it is comparatively easy to produce an effluent containing about 50 p.p.m. suspended solids, irrespective of the strength of the original sewage. This can be accomplished with various types of coagulant at a relatively low cost. In order to clarify sewage to various degrees, with from 10 to 80 p.p.m. suspended solids remaining in the effluent, approximately the same amount of iron (as Fe) is required with all iron salts (ferric chloride, ferric sulfate, chlorinated copperas). For so-called complete clarification of domestic sewage (suspended solids in effluent less than 20 p.p.m.), the quantities of coagulant must be increased materially.

It is, therefore, not a question of the ability to produce any desired effluent, but of purification requirements and cost. Some sewages require more coagulant of a specific type, while others respond better with increased quantities of coagulation aids such as lime. Taking the average results of twelve strong sewages treated with various dosages of ferric chloride and lime (Table I) we find that at prevailing prices for chemicals the lowest cost for complete clarification amounts to $7.80 for chemicals alone.

TABLE I.—*Average Cost of Chemicals for Treating Twelve Strong Domestic Sewages to Complete Clarification with Ferric Chloride and Lime*

$FeCl_3$ P.p.m.	Lime P.p.m.	Cost per M.G.
22	0	$16.06
20	20	15.46
16	40	13.40
8	60	8.42
6	80	7.82
5	100	7.95
4	120	8.08
3	140	8.21

A considerable number of cost estimates have been made, mainly for plants over 5 m.g.d. capacity, and scattered information is available for smaller plants. Results on actual quantities of chemicals used in a number of small plants not yet reported (flows from 0.4 to 4.5 m.g.d.), producing effluents essentially the same, but with different types of sewages to treat, show that the chemical cost for alum treatment alone varies from $6.63 to $14.85 per m.g. (Table II). The cost for coagu-

TABLE II.—*Quantities and Costs of Chemicals*

Plant Number	Sewage Flow M.G.	Character of Sewage; Susp. Solids in p.p.m.	Chemicals and Lb./M.G.	Total Cost $/M.G.
1	1.00	160, domestic	Alum, 529	8.72
2	0.75	250, domestic, septic	Alum, 680	11.22
3	0.50	150, domestic + ind. wastes	Alum, 900	14.85
4	0.40	140, domestic + acid wastes	Alum, 500	6.63
5	4.50	150, domestic + ind. wastes	Alum, 600	10.02
6	1.00	160, domestic	$FeCl_3$, 271; lime, 808	12.33
7	1.40	200, domestic + ind. waste	$FeCl_3$, 140; lime, 250	5.50
8	0.75	250, strong domestic	Copp. 316; Cl 56, Lime 1000	10.21
9	4.50	150, domestic + ind. waste	Copp. 300; Cl 60, Lime 200	7.14
10	4.50	150, domestic + ind. waste	Ferrisul, 600	10.02
11	1.00	160, domestic	Ferrisul, 320; alum 358	11.19

Cost of chemicals per ton:

Alum	$26.50
Lime	10.40
Ferric chloride	60.00
Ferrisul	26.50
Copperas	14.00
Chlorine	100.00

lants using ferric chloride and lime, chlorinated copperas and lime, ferrisul or ferrisul and alum falls within this same range. These costs are for 1940, at prevailing prices. The average for all treatments amounts to $9.80 for chemicals alone. The variation in cost is primarily due to the type of sewage to be treated. If these costs are compared with those published previously we find that they are in general agreement. No matter how we look at the question: chemical costs are high if the sewage is treated with coagulants throughout the year. Where chemical treatment is used seasonally or for partial treatment to relieve the load on existing units, the cost for chemicals is less important. Nevertheless, new and improved coagulants and equipment are still necessary.

New Chemicals for Coagulation

Further developments in chemical treatment appear to depend primarily upon introduction of new and improved chemicals, while better methods of application and better equipment will certainly be developed.

What is the outlook for new chemicals that will produce better results at equal cost or the same results at lower cost than the best available at present?

Silicate-Alum.—The results obtained on a plant scale by Swope [2] with the Baylis silicate-alum method compare favorably with those obtained with ferric chloride alone. Ferric chloride alone produced a B.O.D. reduction of 69 per cent and a suspended solids removal of 74 per cent. The best alum results were 57.7 per cent B.O.D. reduction and 72.8 per cent suspended solids removal, while with the best results of sodium silicate and alum 75.5 and 84.0 per cent were removed, respectively (Table III). The floc with alum and silica was very large,

Table III.—*Results with Alum and Sodium Silicate, and Alum alone.*
Swope: This Journal, **11**, 97 (1939)

	Alum 214 lb./M.G. Sod. Sil. 89 lb./M.G.		Alum 293 lb./M.G.	
	Raw	Red.	Raw	Red.
	P.p.m.	Per cent	P.p.m.	Per cent
Susp. Sol.	138	84.0	151	72.8
B. O. D.	139	75.5	156	57.7
Turbidity	95	62.0	114	42.1

Note: Dosage given in footnote of Table III (Swope article) of 0.2 g./g. SiO_2 and 1.5 g./g. of alum.

whereas that with alum alone was small. The relative costs per million gallons given for this plant are ferric chloride $4.88, alum and silica $3.85 and alum alone $3.32. The conclusion is drawn that treatment with alum and silica was the best for this particular sewage.

The amount of work done on silicate-alum is not sufficient to draw definite conclusions. There seems to be some difficulty in producing a

reproducible, active silicate-alum, aside from the fact that the necessary sulfuric acid is not very pleasant to handle. The additional cost for handling would be rather small.

Sulfalcar.—Sulfalcar, an aluminum hydroxy-chlorosulfate [$Al_2Cl_2SO_4(OH)_2$], has been tried on a plant scale after considerable laboratory investigations. Comparisons were made with alum at the South River, N. J., plant. The South River plant consists essentially of coagulating equipment, flocculating chambers (air), settling tanks with built-in sand filters similar to magnetite filters, vacuum filters for dewatering of raw coagulated sludge, and appurtenances. The sewage is strictly domestic, while the average dry weather flow treated is about 650,000 gallons daily. After considerable experimentation alum treatment was considered best and most economical. Sulfalcar goes readily in solution so that it could be applied with the standard equipment available.

In alum treatment of sewage it has been found that laundry wastes do not readily respond and particular attention was paid to determine the comparative effect of sulfalcar.

Samples of raw sewage, settled sewage and filter effluent were taken every 15 minutes and composited hourly. Sampling began at 8 a.m. and ended at 5 p.m. The principal analyses were B.O.D., suspended solids and turbidity.

A comparison of average results obtained with alum and sulfalcar on domestic sewages and sewages containing considerable laundry wastes is given in Table IV. The suspended solids removal of the

TABLE IV.—*Comparison of Average Results Using Alum and Sulfalcar for Treatment of Sewage*

	Midweek Day Samples		Monday Sewages	
	Alum	Sulfalcar	Alum	Sulfalcar
Dosage, lb.	475	456	550	566
Suspended solids, raw, p.p.m.	208	202	273	274
Removal after settling, per cent	46.6	58.8	49.5	65.3
Removal after settling and filtering, per cent	84.6	86.6	73.3	87.2
B.O.D. raw, p.p.m.	243	223	306	262
Removal after settling, per cent	41.9	48.0	43.4	59.2
Removal after settling and filtering, per cent	60.0	67.7	55.9	70.0

settled sewage was over 12 per cent higher on week days and Monday sewage when sulfalcar was used, while the B.O.D. removal on week days was 6 per cent higher and on Mondays 13 per cent higher. The results on settled and filtered sewage were better, especially on Mondays when suspended solids removal increased from 73.3 to 87.2 and the B.O.D. from 55.9 to 70.0 per cent.

Turbidity measurements for three consecutive Mondays when the sewage was treated with alum, sulfalcar applied at a dosage equal to alum, and equal to half the amount of alum, are of interest, because they give an idea of the greater clarity of the effluents. The average

TABLE V.—*Comparative Average Turbidity Results at South River, New Jersey*

	Alum	Sulfalcar, Dose Equal to Alum	Sulfalcar, Dose Equal to ½ Alum
Raw sewage, p.p.m.	328	323	218
Settled sewage, p.p.m.	225	81	170
Settled and filtered, p.p.m.	119	45	55
Red. settled, per cent	31	74	22
Red. filtered, per cent	64	96	74

results are shown in Table V. With a dosage of sulfalcar equal to the alum dosage turbidity removed after settling and filtering amounted to 96 per cent as compared to 64 per cent for alum.

The comparative cost has been calculated per ton suspended solids and per ton B.O.D. removed, using the same cost for sulfalcar as for alum at $26.00 per ton.

	Mid-Week Sewage	Monday Sewage
Susp. solids removal, alum	$20.60	$21.50
Susp. solids removal, sulfalcar	18.50	17.00
B. O. D. removal, alum	20.60	24.40
B. O. D. removal, sulfalcar	18.50	21.20

It appears from these figures that for equal work performed sulfalcar is from 10 to 15 per cent less costly than alum. This does not take into consideration that clarification is better or that cost increases with greater removal.

The conclusions drawn from the results obtained are:

1. Sulfalcar applied in equal quantities to alum was superior to alum in that it: (*a*) produced better floc formation, (*b*) produced better settling floc, (*c*) was capable of clarifying sewage containing laundry wastes, which could be done with alum only when excessive quantities were used or the sewage was pre-acidified, (*d*) turbidity removal was greater, producing a better looking, sparkling effluent, (*e*) suspended solids removal after settling was 12 per cent higher, (*f*) B.O.D. removal after settling was 6 per cent higher for week days and 13 per cent higher when laundry wastes were present, (*g*) suspended solids removal and B.O.D. reduction after settling and filtering were 10 per cent higher, both on mid-week days and Mondays.

2. No special equipment is necessary other than that used for alum treatment.

3. The cost of sulfalcar per ton suspended solids removed and per ton B.O.D. removed was from 10 to 15 per cent less than for alum.

Observations showed that sludge produced from sulfalcar coagulation was denser and compacted better than sludge from alum treatment. It appeared that sludge obtained from sulfalcar coagulated sewage dewatered better with ferric chloride and lime than when alum was used for coagulation. Cake formation was better and filter loadings in-

creased. More information is required to substantiate this tentative conclusion.

Ferrigel.—Ferrigel is a compound made from ferric chloride and gelatine, glue or certain proteins. The product dissolves readily in sewage and acts rapidly. Considerable experimentation with various sewages shows that it is an effective coagulant for various types of sewages. Detailed results will be published later, but some of the general conclusions may be stated at present.

Ferrigel produces a large, strong, heavy, frequently ball-like, floc which settles quickly. It reduces the amount of ferric chloride for coagulation about 40 per cent. It acts best when sewage and coagulant are stirred for 15 to 30 minutes, similar to established methods of treatment. Use of air for stirring is undesirable. Ferrigel is effective over a pH range of 4.5 to 8.5, with an optimum effect in the range from 4.5 to 6.0, producing an effluent of unusual clarity.

Sludge obtained by treating sewage with ferrigel is more dense and compact than sludge obtained with ferric chloride. It dewaters fresh solids to a degree similar to ferric chloride, but appears to dewater ripe sludge better. It is of considerable importance that sludge obtained by ferrigel treatment of sewage can be dewatered without further additions of chemicals, producing a dry cake quickly, with a sparkling clear effluent. It appears that the material is stable indefinitely. Tests with this material on sulfur black and aniline dye wastes showed that any strength of the wastes could be completely clarified, producing a large ball-like floc, while the sludge obtained was readily dewaterable.

The product is far less corrosive than ferric chloride. It appears that it produces equal clarification results at lower cost than ferric chloride or better results at equal cost.

Future Possibilities

Since we are beginning to learn which substances present in the sewage cause the greatest chemical demand and which cause expansion of sludge we are on the road to find even better chemicals. In general we can cause rapid coagulation and compacting by the destruction of the gel-like structure of sewage solids; or the coagulation and contraction of the particles may be brought about by attacking the compounds responsible for holding the particles in suspension. In present practice we frequently do both, but not necessarily with the best means. Because the relative quantities of the substances causing the gel-like structure and those responsible for dispersion vary with the type of sewage the response of the sewage differs and a universal coagulant is more difficult to produce. The chances that a simple, single chemical can achieve high purification results under all conditions is rather remote. Either a chemical compound with properties capable of accomplishing several of the required functions or a combination of chemicals are necessary to produce such results at low cost.

The new coagulants briefly discussed are indications of future possi-

bilities. It should be kept in mind, however, that chemical treatment is still fundamentally an aid to physical and biological methods of treatment. With improved settling, straining and filtering methods, coagulants provide an important auxiliary for increasing removal of suspended material and for polishing off of effluents, but they do not supplant these physical methods. However, the fact that they aid physical methods is sufficient evidence that chemical treatment processes will continue to be used.

Coagulation as an aid to biological treatment processes has not expanded as much and as rapidly as warranted. Only in a few instances provision has been made in new activated sludge and trickling filter plants for effective utilization of chemicals. Coagulation may be of particular importance in existing biological treatment processes to reduce the load on certain units or improve results. Again, the possibilities have by no means been exhausted.

Great strides have been made in operation procedure and methods of mixing and distribution of the chemicals. One of the more important requirements in coagulation is proper distribution of the chemicals. In many cases this is inadequate or faulty. In addition, good equipment for one set of chemicals may be improper or incorrect for another group of coagulants. Although advances have been made there is still considerable room for equipment manufacturers to improve distribution and mixing.

Ten years of modern chemical treatment have resulted in great popularity with excessive claims, followed by a sobering and better understanding of the place of this primarily auxiliary method. At present there is a tendency to under-estimate the place chemical coagulation can and does fill. We are now at the beginning of renewed interest in improved physical methods of treatment, including settling, stirring, straining and filtering, which possibly may overshadow for some time interest in chemical treatment, but the end of possibilities in chemical treatment is not in sight. Chemical treatment will continue to take a firmer and more definite place among the various processs, becoming a more and more useful tool, in spite of a probable general slowing up of the movement for cleaner streams during the next few years.

Summary

During the last ten years chemical treatment of sewage has gone through a cycle of awakened interest, great popularity and gradual stabilization, with a better understanding of the functions and places it can fill. The most widely used chemicals are alum, ferric chloride and lime, chlorinated copperas and ferrisul. Two new compounds, sulfalcar and ferrigel, appear to be capable of producing better results at the same cost or the same results at a lower cost than alum or ferric chloride. The function of lime may be underestimated. Further improvement of equipment and more effective chemicals are needed. Chemical treatment is primarily an auxiliary treatment in conjunction with biological or physical methods of sewage treatment.

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DISCUSSION OF DR. RUDOLF'S PAPER

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I would like to add to Dr. Rudolf's list of newer chemicals for sewage treatment, the combination copperas-sodium silicate. We used this combination in studies of additional treatment for the West Side Imhoff effluent with considerable success, both with regard to removal of B.O.D. and cost of chemicals. Table I shows some typical lab-

TABLE I.—*Chemical Treatment of Sewage—Laboratory Tests*

Test No.	Chemicals, Lb. per M.G.				Chemical Analysis, p.p.m.		Reduction in B.O.D.	
	Ferric Chloride	Copperas	Alum	Sodium Silicate	Turbidity	B.O.D.	P.p.m.	Per Cent
A	0	0	0	0	59	97		
	200				40	34	63	65.0
		300			80	39	58	59.8
			300	100	35	30	67	69.1
		300		100	20	27	70	72.2
B	0	0	0	0	75	87		
	200				54	28	59	67.8
			300	100	54	30	57	65.5
		300		100	56	23	64	73.5

oratory tests in which copperas-sodium silicate was compared with alum-sodium silicate, ferric chloride, and copperas alone. The combination copperas-sodium silicate gave the best results, removing in one case 72.2 per cent of B.O.D. against 69.1 per cent for alum-sodium silicate and 65.0 per cent for ferric chloride. In the other case copperas-sodium silicate removed 73.5 per cent as against 65.5 and 67.8 per cent for alum-sodium silicate and ferric chloride, respectively.

In Table II, I have shown the results of all runs at the experimental plant, which treated 1.89 m.g.d. The amount of copperas used is arranged in descending scale from 232 pounds per m.g. to 96 lbs. per m.g., averaging 154 pounds. The sodium silicate used averaged 115 pounds and sulfuric acid 15 pounds. The average reduction in B.O.D. obtained with copperas-sodium silicate was 68.6 per cent. The average reduction obtained with ferric chloride was 63.3, ferric chloride and lime 61.0, and chlorinated copperas 51.8 per cent. The per cent reduc-

TABLE II.—*Chemical Treatment of Sewage—Plant Tests*

Coagulant	Operating Period Days	Chemicals, Lb. per M.G.						Chemical Analysis					
								Susp. Solids			B.O.D.		
		Copperas $FeSO_4 \cdot 7H_2O$	Sodium Silicate 42° Be'	Sulfuric Acid 66° Be'	Chlorine Cl_2	Ferric Chloride $FeCl_3$	Lime CaO	Raw p.p.m.	Eff. p.p.m.	Red. %	Raw p.p.m.	Eff. p.p.m.	Red. %
Copperas and Sodium Silicate	10	232	114	14.6				171	51	70.3	98	22	77.6
	21	191	109	13.9				146	56	61.6	119	51	57.1
	5	176	121	15.5				131	31	76.4	67	18	73.2
	15	142	108	13.8				116	37	68.1	78	28	64.1
	10	132	122	15.6				142	35	75.3	85	20	76.5
	7	109	123	15.7				145	36	75.2	76	28	63.2
	17	96	109	13.9				129	40	69.0	78	25	67.9
Av.	85	154	115	15				140	41	70.4	86	27	68.6
Ferric Chloride	57					162		131	39	70.2	90	33	63.3
Ferric Chloride and Lime	121					142	238	133	41	69.2	105	41	61.0
Chlorinated Copperas	62	267			38			133	64	51.9	112	54	51.8

tion of suspended matter was approximately the same for copperas-sodium silicate, ferric chloride and ferric chloride and lime, 70 per cent. Results with chlorinated copperas alone were poor.

I mentioned before that the cost of treatment per m.g. was low. Table III shows the comparative costs for treatment of the weak sew-

TABLE III.—*Chemical Treatment of Sewage—Cost per M.G.*

Chemical Treatment	Cost per Million Gallons, Dollars							Per Cent Reduction B.O.D.
	Copperas @ $16.00 per Ton	Sodium Silicate @ $14.00 per Ton	Sulfuric Acid @ $16.00 per Ton	Chlorine @ $60.00 per Ton	Ferric Chloride @ $40.00 per Ton	Lime @ $10.00 per Ton	Total Cost per M.G.	
Copperas and Sod. Silicate	1.23	0.92	0.12				2.27	68.6
Ferric Chloride					3.24		3.24	63.3
Ferric Chloride and Lime					2.84	1.19	4.03	61.0
Chlorinated Copperas	2.13			1.14			3.27	51.8

age at the West Side Plant. Copperas-sodium silicate gave the best results at the lowest cost, $2.27 per million gallons. The cost for treatment with ferric chloride was $3.24.

We also ran a few tests using sodium silicate and spent steel pickling liquor as a source of copperas. The results are given in Table IV.

TABLE IV.—*Chemical Treatment of Sewage—Steel Pickling Liquor and Sodium Silicate*

Coagulant	Operating Period Days	Chemicals, Lb. per M.G.				Chemical Analysis					
		Pickling Liquor as $FeSO_4 \cdot 7H_2O$	Sodium Silicate 42° Be′	Sulfuric Acid 66° Be′	Lime CaO	Suspended Solids			B.O.D.		
						Raw p.p.m.	Eff. p.p.m.	Red. %	Raw p.p.m.	Eff. p.p.m.	Red. %
Pickling	7	218	120	15.3	—	129	64	50.4	93	45	51.6
Liquor and	8	175	112	14.3	48	127	59	53.5	107	50	53.3
Sodium Silicate	4	222	115	14.7	57	163	46	71.8	136	55	59.5

We found it necessary to neutralize the free acid with lime, but it would have been better to use scrap iron thus increasing the concentration of copperas. These tests were still in the exploratory stage when the experiments were discontinued, but indicate a possible use for this waste.

Dr. Rudolfs mentioned the difficulty of preparing a uniformly active silica solution. We did not find it particularly difficult to prepare a satisfactorily uniform product. However the preparation did require the skill and the constant supervision of a chemist. The greatest disadvantage to the use of "activated" silica, as we see it, is that it must be prepared in batches but even this did not cause us any trouble since each of the two 3000 gallon tanks we had available furnished us a three-day supply and by using them alternately, treatment of sewage proceeded uninterruptedly.

Reference: E. Hurwitz and F. M. Williamson, "The Use of Copperas-Sodium Silicate as a Sewage Coagulant." *This Journal,* 12, 562 (May, 1940).

THE ROLE OF THE TRICKLING FILTER IN SEWAGE PURIFICATION *

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The introduction of the activated sludge process, about a quarter of a century ago, revolutionized sewage purification concepts and, for a while, threatened to relegate the trickling filter to a minor role in sewage treatment, if not to displace it entirely. Twenty-five years of experience has indicated, however, that the trickling filter has certain virtues which, under some conditions, may render it useful and effective where the activated sludge process is doomed to failure. Necessity for finding some method of successfully treating creamery wastes from small Iowa dairies soon taught us that marked fluctuations in the concentration of creamery wastes tended to seriously disturb and disrupt the purifying functions of the activated sludge floc, whereas the trickling filter (probably because its upper layers serve as a sort of equalizing and storage mechanism, thereby partially protecting the lower purifying zones against sudden changes) was found to be much more applicable for treatment of this industrial waste. The change of concept as to criteria of purification also played a vital role in the revival of interest in trickling filters.

In the conventional sewage treatment plant, consisting of sedimentation followed by trickling filters, the action in the settling tank was looked upon as primarily, and in a sense exclusively, mechanical. Such biological action as might take place in the settling tank was considered incidental and more recently it has been recognized that any appreciable biological action would be detrimental, so that chlorination was introduced to reduce such activity to a minimum and, if possible, to arrest it entirely. The filter, on the other hand, was looked upon as a purely biological agent and its mechanical agglomeration functions were either disregarded or minimized so that the efficiency of the trickling filter was evaluated primarily upon the degree of mineralization effected, as measured by nitrification. A highly nitrified effluent can be attained only through aerobic biological oxidation. The introduction of the criterion of oxygen demand reduction (which could be effected by physical and chemical as well as biological agencies) as a measure of purification efficiency, made possible utilization of the trickling filter's capacity for such physico-chemical reductions in B.O.D. This new emphasis on the nature of the desired accomplishment in sewage treatment served to bring filters back into the picture of sewage purification, as it was recognized that properties other than

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biological stabilizing functions such, for example, as their agglomerating capacities, may be profitably and effectively utilized.

The early work on creamery waste treatment, and later on purification of packinghouse wastes, at the Iowa Engineering Experiment Station clearly demonstrated that the commonly held concepts of the purifying properties and capacities of trickling filters were extremely conservative and that slight alterations in the methods of operation would tremendously increase the effectiveness of trickling filters for removing oxygen demanding constituents, though not as nitrifying units, and that the trickling filter might have a very important role as a preliminary process as well as a final purifying mechanism.

It is the purpose of this paper to review briefly a few of the experiments during the decade 1925–35 which led to the introduction of double filtration plants for treating packing house wastes at Mason City and Storm Lake, Iowa, and West Fargo, North Dakota, and to present some data on the performance of full sized plants designed on the basis of these laboratory studies.

Filter Capacity

In some experiments on the efficiency of a small lath filter (2 ft. square and 6 ft. deep) it was observed that the oxygen consumed value of a 1 per cent skim milk solution, applied at 800,000 gal. per acre per day for 14 hours daily, was reduced from 390 to 74 p.p.m. About 214 lb. of oxygen consuming constituents were removed per acre-foot and the effluent was very highly nitrified, an initial concentration of 1.37 p.p.m. nitrates rising to 10.97 p.p.m. Application of a 7 per cent skim milk solution with an oxygen consumed value of 3,095 p.p.m. resulted in the removal of 2,010 lb. oxygen consumed per acre-foot but the effluent was not nitrified, a nitrate content of 2.39 p.p.m. dropping to 1.85 p.p.m.

The tremendous capacity of trickling filters for removing oxygen consuming constituents was evident. With the waste in question the filter clogged rather quickly when these heavy loads were applied, but that merely indicated that a means should be found for de-clogging in order to utilize the maximum purification properties of filters. It appeared that if the cost of de-clogging and disposing of agglomerated constituents were less than standard aerobic processes necessary for complete purification utilization of such a de-cloggable filter might be particularly applicable to the treatment of concentrated industrial wastes, an inference which was later projected into the packinghouse wastes treatment plants at Mason City, Iowa, and West Fargo, North Dakota.

Bottom Ventilation

The importance of thorough bottom ventilation for filters treating creamery wastes was demonstrated by employing cinders, 6 ft. deep, as the filter medium. It was found that without such ventilation the

effluent became acid and B.O.D. reductions were low. Thus, for a waste with a B.O.D. of 984 p.p.m. that of the effluent was 213 p.p.m. in the absence of bottom ventilation, whereas, when well ventilated, the B.O.D. of the filter effluent was only 13 p.p.m. Nitrification was very marked during the period when the filters were well ventilated, the effluent containing 18.8 p.p.m. N as nitrates in contrast to only 1.3 p.p.m. during the period when the filters were not ventilated. Without thorough bottom ventilation the effluents were acid, low in nitrates, but high in organic and ammonia nitrogen, and surface ponding occurred. In contrast, the effluents from the well ventilated filter were alkaline, high in nitrates but low in organic and ammonia nitrogen and the waste flowed freely through the filter.

That trickling filters could be depended upon to remove tremendously greater quantities of B.O.D. constituents from protein (packinghouse) as well as carbohydrate (creamery) wastes than was generally considered to be feasible, was indicated by some observations with a 1 to 3½ in. quartzite aerated filter, 3 ft. square and 10 ft. deep, to which was applied a packinghouse waste with a B.O.D. of 929 p.p.m., at rates of 7 to 10 m.g.a.d.

TABLE I.—*Removal of B.O.D. from Settled Packinghouse Wastes by Aerated Coarse-Rock, Deep (10 ft.) and Washable Shallow (3 ft.) Cinder Filters (Experimental Units)*

	Aerated Rock at 7,000,000 G.P.D.	Washable Cinders at 4,000,000 G.P.D.	
		Series A	Series B
B.O.D. of applied waste	929	665	907
B.O.D. of filter effluent	549	289	447
B.O.D. settled filter effluent	455		
Per cent reduction by filter	40.9	55.5	50.7
Per cent reduction by filter and post-settling	49.9		
Lbs. B.O.D. removed per acre-foot			
By filter only	2,210	4,170	5,100
By filter and post-settling	2,700		
* Over-all per cent reduction			
Pre-settling filtration	58.7	68.8	64.6
Pre- and post-settling, filtration	65.0		
* Over-all lbs. B.O.D. removed per acre-foot			
Pre-settling and filtration	4,550	7,350	8,250
Pre- and post-settling and filtration	5,050		

* Assuming 30 per cent reduction by pre-settling.

From Table I it will be noted that the filter receiving settled waste with a B.O.D. of 929 p.p.m., applied at a rate of 7 m.g.a.d., produced an effluent with 549 p.p.m. B.O.D. and this decreased to 455 p.p.m. on settling. This corresponded to reductions of 40.9 per cent and 49.9

per cent by filtration and filtration followed by post-settling, respectively. On the basis of the filter volume the reductions in B.O.D. were 2,210 lb. per acre-foot by filter action, and 2,700 lb. per acre-foot when filtration was supplemented by a crude hand operated post-sedimentation unit. Assuming an efficiency of 30 per cent reduction in B.O.D. by settling before filtration, the over-all efficiency of pre-settling followed by filtration would be 58.7 per cent, rising to 65 per cent if followed by post-settling, and the reductions in B.O.D. on the basis of filter volume would, under these conditions, have been 4,550 lb. and 5,050 lb., respectively.

The unit was in continuous successful operation for over six months but on cessation of bottom aeration ponding developed slowly, though the filter continued to function quite well; a larger filling material, it was thought, could be successfully employed without forced aeration. These results indicated that this relatively high rate of filtration might serve very effectively as a preliminary treatment, for highly concentrated wastes.

A plant embodying this type of preliminary treatment (coarse rock at 8 m.g.a.d.) followed by settling and secondary filtration was installed in Storm Lake, Iowa, in 1936 and has successfully treated a mixed packinghouse and domestic sewage.

Another process investigated consisted of a shallow, 3 ft. deep, washable, cinder filter to which packinghouse sewage was applied at a rate of 4 m.g.a.d. In one series of experiments it was observed that a B.O.D. of 665 p.p.m. in the settled applied waste dropped to 289 p.p.m., a decrease of 55.5 per cent, and in another series, a B.O.D. of 907 p.p.m. in the settled applied waste fell to 447 p.p.m. in the filter effluent, a reduction of 50.7 per cent. Evaluating the reductions of B.O.D. on the basis of filter volume this would amount to 4,170 and 5,100 lb. per acre-foot for the respective series of observations. Assuming 30 per cent reduction by pre-settling, the overall reduction in B.O.D. effected in the two series of observations by pre-settling and filtration would have been 68.8 per cent and 64.6 per cent. Evaluating these reductions on the basis of the volume of the filter would show values of 7,350 and 8,250 lb. B.O.D. removed per acre-foot by pre-settling and filtration for the two runs.

Dosing Cycle

The effect of the dosing cycle was observed to be particularly marked and significant when employing coarse-grained filling materials and the results disclosed that, contrary to the opinion previously held by a large proportion of sewage treatment personnel—that long intervals between doses were necessary and indispensable to proper functioning of trickling filters—a very short period between doses was conducive to maximum efficiency. In Table II are shown the results obtained with various dosing cycles (2½ to 20 minutes). When skim milk was applied to a quartzite (1 to 3½ inches) filter 6 ft. deep, at

an average rate of 750,000 gallons per acre per day, it will be noted that B.O.D.'s of 975 to 1030 p.p.m. were reduced to 91 to 95 p.p.m. when employing short cycles (2½ to 7 minutes) whereas the long dosing cycle (20 to 22 minutes) yielded an effluent with 229 p.p.m. B.O.D.

With fine-grained materials, such as cinders, the dosing cycle had very little influence on the purification effected, but for the coarse-grained (1 to 3½ inch) rock, the shorter the dosing cycle, the more efficient was the purification effected.

TABLE II.—*Effect of Dosing Cycle on Reduction of B.O.D. by Coarse-Grained Trickling Filter Receiving Skim Milk*

Dosing Cycle	Raw Waste	Effluent	Per Cent Reduction B.O.D.
	B.O.D. (in p.p.m.)		
2½ Minutes	1,010	95	90.6
5–7 Minutes	1,060	91	91.4
10–12 Min.	975	127	87.0
20–22 Min.	1,030	229	77.8

The influence of the dosing cycle on the rate of run-off and the B.O.D. of the effluents at different periods between doses is of particular interest from the standpoint of sampling and it might therefore be worthy of some special consideration.

A series of consecutive 250 ml. portions of effluent were collected in bottles continuously for one or more complete cycles, daily, and the time of discharge of these quantities noted. B.O.D. determinations were then made on samples representing maximum and minimum rates of run-off, or discharge, as well as for the total volume discharged in one complete dosing cycle. In Table III are shown the distributions of the rates of discharge of the effluent from a filter receiving waste at a rate of 0.75 m.g.a.d., for various dosing cycles.

The effect of the dosing cycle may be seen by comparing the rates of run off at 2½ minutes with the 20 to 22 minute cycle. With the short cycle, all of the effluent was leaving the filter at approximately the rate at which it was being applied, *i.e.* 100 per cent of the effluent left the filter at rates of 0.6 to 0.9 m.g.a.d. or an average rate of 0.75 m.g.a.d. In contrast to this, when employing a 20 to 22 minute cycle, only 11.2 per cent was being discharged at this corresponding rate. A large proportion of the waste was leaving the filter at rates very much higher or very much lower than that of the rate of application. Attention is called particularly to the fact that 45.5 per cent of the effluent was running off at an average rate of 5.1 m.g.a.d. or about seven times the rate of application, while 13 per cent of the samples were issuing from the filter at rates of less than 0.26 m.g.a.d. Whereas the maximum deviation of the rate of outflow of individual samples from the mean rate was only 11.5 per cent when operating on a 2½ minute cycle it rose to 34.2 per cent on the 5 to 10 minute cycle, 42.1 per cent

TABLE III.—*Effect of Dosing Cycle on Distribution of Rates of Discharge of Waste from Filter*

Dosing Cycle	2½ Minutes	5–7 Minutes	10–12 Minutes	20–22 Minutes
Average Rate of Discharge (m.g.a.d.)	Per Cent of Applied Waste Discharged in Effluent			
5.10			3.3	45.5
1.80			10.0	8.4
1.10		25	15.0	5.6
0.75	100	36	41.6	11.2
0.51		39	28.4	9.8
0.35			1.7	5.6
0.26				5.6
0.20				8.3
Number of consecutive samples observed	28	28	60	143
B.O.D. effluent	95	91	127	229
B.O.D. at minimum rate of discharge		72	48	24
B.O.D. at maximum rate of discharge		108	172	428
Ratio B.O.D.: max./min.		1.57	4.18	19.8

on the 10 to 12 minute cycle and to 113 per cent for the 20 to 22 minute cycle.

The B.O.D.'s of the effluents were in direct relationship to the rate of runoff, that is, the higher the rate of runoff, the greater was the B.O.D.

The average B.O.D. of the effluent for the 2½ minute cycle was 95 p.p.m.

For the 5 minute cycle, the average B.O.D. was 91 p.p.m., the B.O.D.'s of individual samples ranging from 72 to 108 p.p.m. the ratio of maximum to minimum B.O.D. being 1.57.

For the 10 to 12 minute cycle the variations were considerably greater, ranging from 48 to 172 p.p.m. the ratio of B.O.D. at maximum to that at minimum rate of discharge rising to 4.18.

With the 20 to 22 minute cycle tremendous variations in B.O.D. were obtained for the individual samples. At the minimum rate of runoff the B.O.D. of the effluent was only 24 p.p.m. whereas at the maximum rate of discharge it rose to 428 p.p.m., the ratio of the maximum to the minimum B.O.D. being 19.8.

With longer dosing cycles, employing coarse filling material the rate of runoff of the effluent was strikingly synchronized with the application of waste, the maximum runoff rate following very shortly (becoming manifest within a minute) after the discharge of a dose on to the filter, with the result that there were surges of effluent which contained relatively large portions of poorly purified sewage. These fluctuations indicate that unless the runoff cycle is carefully taken into consideration during sampling, exceedingly low or high rates of puri-

fication may be obtained depending upon the stage in the runoff cycle at which a sample is collected. Thus, for example, purification efficiencies as low as 58 per cent or as high as 98 per cent could have been reported for this particular filter depending upon the point in the runoff cycle at which the samples were collected. It might be noted at this point that, in order to eliminate errors due to fluctuation in the B.O.D. of the effluents at various periods between doses, the volume of effluent collected in these studies for the purpose of ascertaining average efficiency was equal to that discharged in a single dose when employing the long dosing cycle (20 to 22 minutes) and to two to four times the volume discharging on the filter when the shorter dosing cycles were employed.

In general it may be stated that the shorter the dosing cycle, the more uniform is the rate of runoff and that the more uniform the rate of runoff the more nearly is being approached the maximum efficiency of a filter for the load it is receiving.

Rate of Application

The foregoing observations demonstrated quite clearly that trickling filters had not, in the past, been utilized to anything like their full capacity. This is particularly true with respect to the agglomerating properties of filters, as may be seen from the following example. To a small unit, 2 ft. square and 6 ft. deep, the filter medium consisting of 1 in. raschig rings (hollow clay cylinders), was applied settled domestic sewage at various rates. The result for the 2.0 to 16.0 m.g.a.d.

Table IV.—*Relation of Rate of Application of Settled Domestic Sewage to Biological and Physico-Chemical Reduction of B.O.D. by Filtration and Post-Settling*

Dosing Rate M.G.D.	B.O.D.			Per Cent Reduction B.O.D.	
	Raw	Filter Effluent	Settled Effluent	Filter Only	Filter Eff. Settled
2	186	46	17	75.3	90.9
16	226	115	24	49.1	89.4

	Pounds B.O.D. Removed Per Acre-Foot Filter			Ratio B.O.D. Removed $\left(\frac{\text{Post-Settling}}{\text{Filter}}\right)$
	Filter Only	Post-Settling	Total	
2	389	80	469	20.5%
16	2480	2020	4500	81.5%

	Org. N.*			NH_3*			NO_3*	
	Raw	Eff.	Per Cent Red.	Raw	Eff.	Per Cent Red.	Raw	Eff.
2	12.4	6.5	47.6	43.9	9.9	77.5	0.4	16.9
16	11.8	11.7	0.9	24.6	18.6	24.5	Tr.	3.5

* In p.p.m.—filter effluent not settled.

rates are summarized in Table IV. The B.O.D. reduction by the filter alone at the higher rate (16.0 m.g.a.d.) was only 49.1 per cent as compared with 75.3 per cent at the lower rate of application (2.0 m.g.a.d.), but the actual removal of biological oxygen demanding constituents was very much greater as indicated by the fact that there was removed only 389 lb. of B.O.D. per acre-foot at the 2.0 m.g.a.d. rate as compared with 2,480 lb. at the 16.0 m.g.a.d. rate. On settling the filter effluent, the over-all per cent reduction at the 2.0 m.g.a.d. rate rose slightly to 90.9 per cent whereas for the 16.0 m.g.a.d. rate it rose to 89.4 per cent so that as a result of settling the filter effluent, only 80 pounds more of B.O.D. was removed, when dealing with the lower rate, but at the high rate of application an additional 2,020 pounds was removed. This indicates very clearly that one of the chief functions of the high-rate filter is that of agglomeration of finely suspended and colloidal oxygen-demanding constituents into readily settleable suspended particles.

It will further be noted that at the low rate of application the ammonia and organic nitrogen values were reduced 77.5 and 47.6 per cent, respectively, and the effluent was very highly nitrified (16.9 p.p.m. N as NO_3). In contrast to this, at the high rate, there was no change in the organic nitrogen, only 24 per cent reduction in ammonia, and nitrification was poor. These results are another indication of the importance of the agglomerating, as compared to biological oxidation, characteristics of the high rate filters.

Biological and Physico-Chemical Properties of Trickling Filters

The trickling filter may be considered as a mass of small pieces of inert material which provides a large surface on which bacteria and other organisms, brought to it by the sewage, accumulate and there develop jelly-like matrixes which function as purification zones. As sewage comes in contact with these biological films its colloidal and finely suspended constituents are agglomerated into suspended particles; the soluble substances diffuse into these films, there to be acted upon by the inhabitant microorganisms or their enzymes. The agglomerated materials may be adsorbed to the purifying film, later to be further degraded by enzymic action before they can be acted upon in a manner analogous to the soluble sewage constituents, when operating at customary low rates of filtration, but they are, for the most part, removed mechanically as suspended particles, when filters are operated at high rates. A filter therefore acts both as a physico-chemical-colloider—really a decolloider or preferably an agglomerator of colloidal and finely suspended constituents—and as a biological transformer. To the extent that the agglomerated materials might be removed and disposed of by some more economical process, such as digestion and particularly lagooning, the biological activities of trickling filters could be conserved for action on soluble sewage constituents.

As the sewage passes down through the filling material of the filter

it is continually modified in composition by biological agencies so that at any point in the filter the nature of the dissolved and other constituents, as well as the oxidation-reduction potential of the medium, is different from that a short distance above or below. These factors markedly influence and determine the characteristics of the flora and fauna with the result that there is encountered a gradual change in types of bacteria and other microorganisms as the sewage progresses from the top to the bottom of the filter. In fact, there is set up a series of zones of microbial action which intergrade into one another but are nevertheless distinct. Thus, in the upper strata of the low-rate filter, organisms predominate which are capable of attacking proteins and amino acids with liberation of such compounds as ammonia and hydrogen sulfide, and decomposing carbohydrates with the production of acids. At an intermediate depth, bacteria which can activate these end-products and further oxidize them, abound. As the bottom of the filter is approached, the nitrifying (ammonia and nitrite oxidizing) and the sulfur-oxidizing bacteria find a suitable environment for their activities. Anything which would be conducive to establishment and maintenance of these zones of biological activity, such for example, as equalization of flow, short dosing cycles to eliminate surges, and physical separation of those portions of the filter which function primarily for the later stage of oxidation (nitrification) from those portions associated primarily with peptonizing, ammonifying and physico-chemical agglomerating activities, would be conducive to optimum filter efficiency. If the primary or upper layers of a filter be so constructed that they might be readily declogged by backwashing, or if the primary filter is of coarse material operated at a high rate so that the agglomerated solids are washed out, and if provision is made to prevent these agglomerated suspended solids generated in these types of filters from reaching what would normally be the lower portion of a single filter, as, for example, by interposing a suitable settling tank, the capacity of filters for removing oxygen demanding constituents could be tremendously increased.

Several plants have been installed on these principles. The first of this type using a washable filter was built in 1928 and put in operation at the Decker Packing Company at Mason City, Iowa, in 1929, to replace an activated sludge plant which had unsuccessfully struggled with the problem for about seven years. Its design was based upon the results of a year's investigation under the direction of the author supported in part by a grant from the Decker Packing Company to the Iowa Engineering Experiment Station. The Currie Engineering Company of Webster City, Iowa, designed this pioneer plant which consists of primary settling and flow equalizing tanks, followed by primary filtration on ¼ acre of a shallow fine-grained washable filter the effluent from which is settled in a circular clarifier. This clarifier effluent is applied to a deep 8 ft. secondary filter ½ acre in area, which is followed by final sedimentation in a modified Dorr clarifier. The primary filter is subdivided into eight units, each 1/32 of an acre in

area and 3 ft. deep, having a total volume of ¾ of an acre-foot, and the filling material for this consists of ½ to 1 in. dolomite. The secondary filter consists of two ¼ acre units 8 ft. deep, having a volume of 4 acre-feet, the filling material being 1 to 3 in. dolomite. The waste is applied by means of floating cone-nozzles on the primary and stationary nozzles on the secondary filters, with a dosing cycle of approximately seven minutes.

The plant was designed for 750,000 gallons with a maximum rate of flow of 1,000,000 gallons per day and it was anticipated that with a maximum B.O.D. of 1,000 p.p.m. for the raw waste, over-all reduction of at least 85 to 90 per cent would be attained.

In 1935, Armour and Company purchased the Decker plant and became vitally interested in its sewage disposal plant because a very acute stream pollution condition had developed in the Sheyenne River, which was receiving the packinghouse waste of the Armour and Company plant at West Fargo, North Dakota. The author's observations at the Decker plant, for a period of about six years, and continued laboratory scale experiments disclosed possible modifications, particularly in the design of the primary filter which, it was felt, would not only materially improve efficiency of operation but might reduce the size of the filter unit.

The suggested modifications included: deepening of the primary washable filter to 6 feet; increasing the rate of application to at least 6 to 8 m.g.a.d.; and utilization of the shortest feasible dosing cycle, preferably two minutes, or less. The latter, it might be pointed out, was urged for the original Decker plant but in 1928 the diffidence of designing engineers to utilize travelling distributers and the supposed unavailability of suitable ones, mitigated against its incorporation into the Decker plant at that time.

In 1937, a plant was designed by Alvord, Burdick and Howson for West Fargo, North Dakota,* incorporating the essential principles of the Decker plant together with the suggested modifications and engineering features which give greater flexibility in operation, to take care of 700,000 gallons of packinghouse waste per day with an estimated B.O.D. of 1,000 p.p.m. or about 6,000 pounds of B.O.D. per day.

The plant consists of a fine screen, grit and grease removal units, a flocculation unit and primary sedimentation in a straight-line clarifier, followed by treatment on ⅛ acre primary washable-filters. The effluents from the filters are settled in a Dorr clarifier, from which the supernatant liquid is applied to ½ acre of filters, followed by final sedimentation in a Dorr circular clarifier. All sludges are lagooned.

The primary washable-filters consist of four circular units, each 1/32 acre in area and 6 ft. deep, having a total area of ⅛ acre and volume of ¾ acre-foot, and the filling material is 1 to 2 in. granite. The secondary filters, two in number, are of similar design but each is ¼ acre in area, having a total area of ½ acre and volume of 3 acre-feet,

* This plant has recently been described in a paper by L. R. Howson in the Official Bulletin, North Dakota Water and Sewage Conference, September, 1939.

so arranged that they can be operated in parallel or in series. Dosing is effected by means of rotary-arm distributors which make very short dosing cycles feasible, and the rates of application have been approximately 5.6 m.g.a.d. on the primary and 1.4 m.g.a.d. on the secondary filters, when operated in parallel, or 2.8 m.g.a.d. if the latter are employed in series.

In Table V are shown purifications effected at the Decker plant in 1933 and at the West Fargo plant in 1938–39. The data on the latter plant are based on the report by Mr. Howson, previously referred to, assuming that the primary clarification effected a reduction of 33 per cent B.O.D., his report of an initial B.O.D. of 1,000 p.p.m., 65 to 75 per cent reduction by primary filtration and settling, and an over-all reduction of 95 per cent.

TABLE V.—*Purification of Packing House Wastes by Various Units of Plants at Mason City, Ia., and West Fargo, N. D.*

Year	Mason City, Ia. 1933			West Fargo, N. D.* 1939		
Unit	B.O.D.	Per Cent Red. by Unit	Per Cent Red. Over-all	B.O.D.	Per Cent Red. by Unit	Per Cent Red. Over-all
Raw waste	1437			1000		
Primary clarifier	1020	29.5	29.5	667	33	33
Prim. washable filter int. clar.	534	46.6	62.8	300	55	70
Secondary filter and final clar.	82	84.7	94.3	50	83.3	95

* Computed on basis of Howson published report.

A more detailed picture of the efficiency of the various units in the Mason City plant may be obtained from an examination of Figs. 1 and 2. For the year 1933, 50 per cent of the applied wastes had B.O.D.'s of between 700 to 1,400 p.p.m., while 50 per cent of the final effluents gave B.O.D.'s of 20 to 56 p.p.m. The B.O.D. of the next higher 30 per cent of the samples of applied wastes was between 1,400 and 1,800 p.p.m. and the effluents between 56 and 100 p.p.m. Finally, 20 per cent of the raw wastes showed B.O.D.'s of over 1,800 p.p.m. (2 per cent over 2,500 p.p.m.), and 20 per cent of the final effluents were over 100 p.p.m. (2 per cent over 250 p.p.m.).

In Table VI are shown the relative efficiencies of primary and secondary filters at Mason City and West Fargo on the basis of the quantities of B.O.D. removed in comparison with a standard filter one acre in area and 6 feet deep, treating a waste with a B.O.D. of 240 p.p.m. at the customary rate of 2.0 m.g.a.d., or 0.33 m.g. per acre-foot, per day.

The quantity of B.O.D. removed by standard practice filtration and post settling was 397 lb. per acre-foot compared with 3,240 lb. by the primary filter at Mason City and 2,852 lb. at West Fargo. Secondary filtration and settling at the latter two cities removed an additional 560

lb. and 493 lb. per acre-foot at Mason City and West Fargo, respectively.

Comparing the accomplishments of the various systems on the basis of removals effected by all available filter units and post-settling, the figures are 397 lb. for standard practice: 988 lb. at Mason City and 965 lb. per acre-foot of filter at West Fargo.

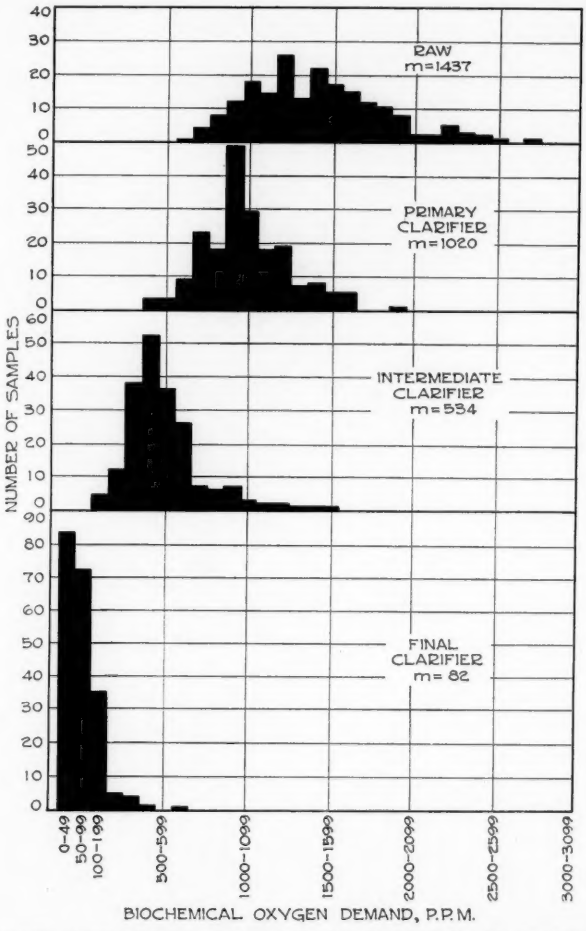

FIG. 1.—Purification of packinghouse wastes at Decker Packing Co., Mason City, Iowa—1933.

If the overall reduction in B.O.D. is expressed on the basis of a unit volume of filter employed, as has been the practice in some reports, the removals effected were 597 lb. per acre-foot for standard practice as compared with 1,430 to 1,475 lb. per acre-foot by the double filtration system and 5,420 to 6,000 lb. per acre-foot at the stage of primary filtration and intermediate clarification.

The trickling filter action may be visualized briefly as follows:

Under standard practice, operating at a rate of 2.0 to 3.0 m.g.a.d., the upper portion of the filter functions as an agglomerating mechanism and includes zones of glycosis and proteolysis, where acid is produced from carbon compounds, and nitrogenous materials are ammonified;

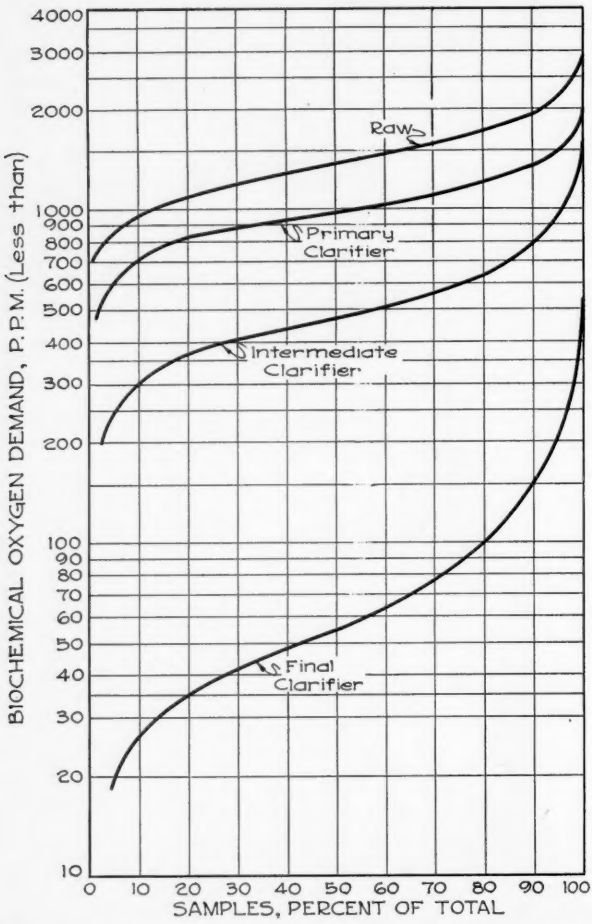

FIG. 2.—Purification of packinghouse wastes at Decker Packing Co., Mason City, Iowa—1933.

the action is primarily analytic (except in so far as microorganisms and their accompanying zoogleal matrixes are being synthesized), and to a considerable extent is due to intramolecular oxidations. These analytic degradations may be effected under either anaerobic or aerobic conditions. In the lower portions of the filter are encountered zones of nitrification and alkalinization.

At high rates of application, the filter acts particularly as an agglomerator (and such biological transformations as are produced are

TABLE VI.—*Comparison of Efficiency of Various Systems of Trickling Filters*

	Domestic Sewage (Stand. Practice)	Packinghouse Wastes (serial filtration)	
		Mason City 1933	West Fargo 1938–39*
Volume of waste treated	2,000,000	600,000	700,000
B.O.D. of raw waste in p.p.m.	240	1,437	1,000
B.O.D. of raw waste in pounds	4,000	7,185	5,800
Primary Clarifier. Pounds B.O.D. removed	1,200	2,085	1,924
Primary Washable Filter and Intermediate Clarifier			
Area of filter (in acres)	1	0.25	0.125
Volume of filter (in acre-feet)	6	0.75	0.75
Rate of application (per acre)	2,000,000	2,400,000	5,600,000
Rate of application (per acre-foot)	333,000	800,000	933,000
B.O.D. removed by unit (in pounds)	2,380	2,434	2,138
B.O.D. removed by unit (pounds per acre-foot)	397	3,240	2,852
Secondary Filter and Final Clarifier			
Area of filter (in acres)		0.50	0.5
Volume of filter (in acre-feet)		4.00	3.0
Rate of application (per acre)		1,200,000	1,400,000
Rate of application (per acre-foot)		300,000	467,000
B.O.D. removed by unit (in pounds)		2,260	1,478
B.O.D. removed by unit (in pounds per acre-foot)		560	493
Combined Filters and Post-settling			
Area of filter (in acres)	1	0.75	0.625
Volume of filters (in acre-feet)	6	4.75	3.75
B.O.D. removed (in pounds)	2,380	4,694	3,619
B.O.D. removed (per acre-foot)	397	988	965
Combined Primary Washable Filter with Pre- and Post-settling			
Total B.O.D. removed (in pounds)	3,580	4,519	4,062
B.O.D. removed expressed as pounds per acre-foot of filter	597	6,000	5,420
All Units Combined			
Total B.O.D. removed (in pounds)	3,580	6,779	5,540
B.O.D. removed (expressed as pounds per acre-foot of filter)	597	1,430	1,475

* Computed on basis of published paper by Howson assuming 33 per cent reduction by primary clarification.

primarily intramolecular oxidations for which highly aerobic conditions are not as essential as is the case for nitrification), while the nitrifying properties of such filters are markedly suppressed or they may even be completely eliminated.

In normal operation of low-rate trickling filters, post-sedimentation of the filter effluent is necessary for the removal of sloughings which consist primarily of suspended particles which had functioned as purifying films and had been dislodged by the action of higher forms of organisms, such as worms. When employing rapid rates of filtration, the post-settling tank serves to remove the agglomerated sewage constituents washed out from the filter before they had become incorporated into the purification films.

SUMMARY AND CONCLUSIONS

With coarse-grained filters, short dosing cycles are conducive to a more uniform rate of discharge and materially increased efficiency. The more uniform the rate of discharge from a filter the more nearly is being approached the maximum efficiency of the unit for the load which it is receiving.

Highly concentrated wastes, with B.O.D.'s up to 3,000 p.p.m., have been effectively treated by series filtration with a settling tank inter-

posed between the filters for the purpose of removing agglomerated colloidal and finely suspended matters effected by a washable or coarse-grained high-rate primary filter.

The term "colloider," for describing the transformation of colloidal and finely suspended materials into substances which settle readily, is considered a misnomer. The action is really that of a "decolloider" and the term "agglomerator" is suggested as more descriptive of what is actually occurring.

Emphasis on the nitrification properties of filters, in the past, has been an important factor responsible for failure to recognize the tremendous capacity of filters to remove B.O.D. constituents by their agglomerating properties.

Fine-grained trickling filters of the washable type and coarse-grained high-rate filters may be effectively employed for the removal of large quantities of B.O.D. constituents or for reduction of excessive fluctuations in concentration of wastes reaching a final process of purification—activated sludge or final trickling filter treatment.

Removals of 4,000 to 6,000 lb. of B.O.D. per acre-foot are feasible with fine-grained, shallow, washable, or with coarse-grained, deep, high rate trickling filters combined with pre and post clarification.

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Plant Operation

NEW DEVELOPMENTS IN ACTIVATED SLUDGE PLANT OPERATION *

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The control of nearly all large activated sludge plants is under scientific supervision, a requisite for efficient and economical operation. Since the process is biochemical in nature, laboratory data are essential for the control of the process as well as for determination of the results accomplished. Some of the variables under direct control of the operator are the rate of application of air, the concentration of suspended solids in the aeration tank and the proportion of sludge return. Of these, the control of the air supply which governs the cost for power, is most important.

The best aids to operation are the control of the dissolved oxygen in the aeration tanks, the sludge index, the microscopic examination and the daily chemical analyses. The dissolved oxygen, the sludge index and the concentration of solids in the aeration tank depend upon the characteristics of the sewage and the sludge and vary considerably among well operated plants. For example, Palmer [1] states that at the Chicago North Side Plant, the liquor leaving the aeration tanks should contain 2.0 p.p.m. of dissolved oxygen. At Wards Island it has been found desirable to have about 5.0 p.p.m. at all times. The sludge index (Donaldson) averaged 1.7 at Tallmans Island for nine months of 1939–1940, 1.37 at the Chicago North Side Plant for 1938,[2] 0.66 at Wards Island for 1939 and about 0.50 at San Antonio.[3] (*Editor's Note.* For computing sludge index as given in Standard Methods, divide Donaldson index into 100.) The concentration of solids permissible in the aeration tank depends largely upon the settling qualities of the sludge. The better the sludge settles, the higher may be the concentration of solids. The optimum concentration, however, is still a matter of opinion. Actual values vary from an average of slightly more than 600 p.p.m. at Providence [4] to about 4000 at Milwaukee [5] with an average at many plants between 1500 and 2500 p.p.m. At Wards Island best results are obtained with about 1500 p.p.m.

A great deal of experimental work has been done by Bloodgood, Kessler, Nichols, Ruchhoft, Sawyer and others with equipment designed to measure the consumption of oxygen by activated sludge and mixtures of activated sludge and sewage under various conditions. Important results have been obtained to explain the mechanism of the reaction.

* Presented at the First Annual Convention of the Sewage Works Federation, Chicago, Ill., Oct. 3, 1940.

Bloodgood is using the results of his tests to control the operation of the Indianapolis plant but apparatus of this type is not in general use as an aid to plant control.

For more than eighteen months a daily microscopic examination of the aeration tank liquor has been made at Wards Island as an aid to the control of the activated sludge process. These examinations have been helpful, particularly in anticipating operating difficulties caused by filamentous bacteria. At times of underaeration, large numbers of amoeba

FIG. 1.—Typical activated sludge at Wards Island plant.

and arcella, one of the amoeboid group, are common. With a proper biological balance, the zooglea is compact and large numbers of ciliates, both free swimming and stalked, are found with few or no flagellates, amoeba or filamentous bacteria. Figure 1 shows a typical Wards Island sludge. Occasionally the aeration tanks have contained a preponderance of filamentous bacteria, such as shown in Fig. 2, and bulking is almost certain under such conditions. No particular significance has been observed as to the presence or absence of flagellates.

Bulking

Bulking is also commonly caused by continued high volatile matter in the suspended solids in the effluent from the primary tanks. It has frequently been observed that bulking occurs during periods of drought but disappears almost immediately after a heavy rainfall. At Wards Island during periods of low rainfall, the volatile matter in the suspended solids in the primary effluent commonly reaches 90 per cent.

Fig. 2.—Activated sludge containing large amounts of filamentous bacteria.

The sludge becomes fluffy, the index goes down and bulking may result. After a heavy rain, the percentage of volatile matter drops perhaps to 60 and almost immediately the sludge regains its normal settling characteristics.

Chlorination of return sludge has been successful at Lima, Ohio,[7] Morristown, N. J.,[8] Houston, Texas[9] and elsewhere. It is generally believed that chlorine is most effective in combating bulking caused by microorganisms. Bulking at Wards Island is caused mainly by high volatile solids but occasionally by filamentous organisms. The addi-

tion of chlorine to the return sludge has helped to control this bulking. For six months, two batteries, each treating an average of more than 50 m.g.d. of sewage, were operated as nearly the same as possible, except that an average of 1.8 p.p.m. of chlorine was added to the return sludge of one battery. In the battery using chlorine, the settling characteristics, as measured by the sludge index, were about 35 per cent better than in the control battery. Then bulking in the control battery made necessary the chlorination of the return sludge in both batteries. Over a period of eight months, with an average chlorine treatment of about 2.5 p.p.m., the sludge index in both batteries averaged about 0.75, the same as for the chlorinated battery during the previous six months period. Filamentous bacteria have not been present in objectionable quantities during chlorination. Care must be taken to add the proper amount of chlorine, as too little has no effect and too much produces a decidedly milky appearance, the result of breaking down the floc.

Effect of Volatile Matter

One of the variables not usually under control of the operator and one not sufficiently well emphasized is the concentration of volatile matter in the solids. As has been mentioned, the concentration of volatile matter affects the settling qualities of the sludge and hence the sludge index. It also has a great effect on the concentration of activated sludge in the settling tanks. In general, as the volatile matter increases, the concentration of solids and the sludge index decrease. This relationship is clearly shown in the results from the Wards Island and Tallmans Island plants. The sewage contributory to both plants is from combined systems. Wards Island receives sewage from the lower part of the Bronx and the upper part of Manhattan, sections densely populated and well paved. The Tallmans Island plant serves a part of Queens and much of this section is unpaved. The concentrations of volatile matter in the sewage and in the excess activated sludge vary within narrow limits at Wards Island but widely at Tallmans Island.

The values shown in Tables I and II and Figs. 3 and 4 were obtained by grouping the sludge index and the daily solids results on the excess

Table I.—*Relationship between Sludge Index and Percentage of Solids and Volatile Matter in Excess Sludge*

Wards Island (1939)

	Per Cent Solids	Per Cent Volatile	Sludge Index (Donaldson)	Number of Observations
	2.67	64.8	1.09	1
	2.70	68.5	.84	26
	2.38	72.8	.75	118
	2.23	77.2	.63	153
	2.02	81.6	.45	59
	1.91	85.5	.40	2
Weighted Average.....	2.27	75.9	.66	

TABLE II.—*Relationship between Sludge Index and Percentage of Solids and Volatile Matter in Excess Sludge*

Tallmans Island (Sept. 1939–May, 1940)

	Per Cent Solids	Per Cent Volatile	Sludge Index (Donaldson)	Number of Observations
	8.84	38.1	2.6	6
	6.40	41.9	3.3	16
	5.68	47.9	2.2	19
	4.49	52.9	1.9	39
	4.10	57.5	1.7	52
	3.56	62.6	1.4	71
	3.52	67.0	1.4	39
	3.27	71.6	1.4	13
	2.81	77.0	1.2	3
Weighted Average.....	4.23	58.5	1.7	

sludge according to the percentage of volatile matter in the sludge and averaging the results in each group. For Wards Island, more than 75 per cent of the volatile solids values were within the limits 70.0 and 79.9 per cent. The average for the year was 75.9 per cent, which is rather high. It is very difficult to thicken the excess activated sludge. Concentrations of 3.5 per cent are unusual and sludges heavier than 3.0 per cent solids are considered satisfactory. At Tallmans Island the per-

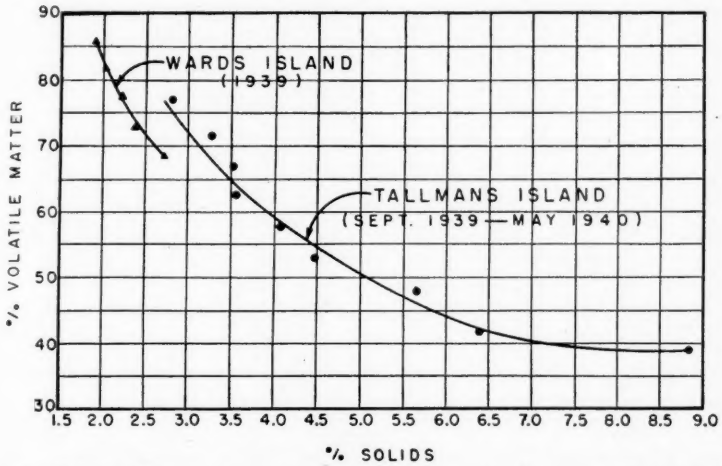

FIG. 3.—Relation between per cent solids and volatile matter in excess activated sludge.

centage of volatile solids in the excess sludge is much more variable and the average of 58.5 per cent was very much lower. In a total of 258 observations, six were less than 40 per cent volatile and more than half of the total results were less than 60 per cent volatile. Solids concentrations of 8 or even 9 per cent are not uncommon. Figure 3 shows clearly that on the average, as the concentration of volatile matter increases, the concentration of solids decreases.

The relationship between the percentage of volatile solids in the excess sludge and the sludge index is shown in Fig. 4. As was the case with the solids, the sludge index decreases with increasing concentration of volatile solids. The Wards Island curves are not direct extensions of those from the Tallmans Island data but are placed to the left. Even in the same plant, there is some evidence that the location of the curves along the abscissa depends upon the efficiency of sludge concentration. With improved methods of concentration of sludge, the curves move to the right, the slope remaining about the same.

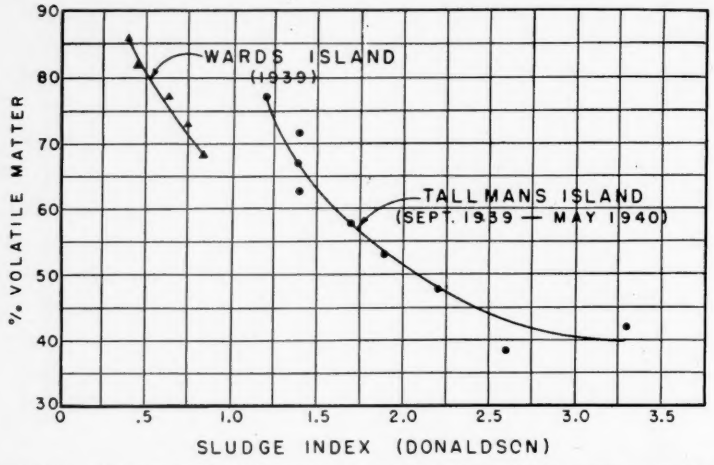

FIG. 4.—Relation between sludge index and per cent volatile matter in excess activated sludge.

It appears from these values that the sludge index is a relative figure, especially as an indication of bulking. For example, the Wards Island plant operates very satisfactorily with a low index, averaging for 1939 only 0.66. The Tallmans Island plant also operates satisfactorily, but with a much higher index, averaging for nine months 1.7. It is quite likely that an average index of 0.66 at the Tallmans Island plant would indicate continuous bulking. However, an average index of 1.7 at Wards Island would probably make operation much easier. In general, it is not necessary to maintain a better average index than is required to produce a satisfactory effluent and sludge.

The relationship between the concentration of volatile solids in the primary tank effluent and the excess activated sludge is not so clear. It is true that in the monthly averages the volatile solids in the primary effluent and in the excess activated sludge follow each other fairly closely, with the volatile solids in the primary effluent somewhat higher than in the sludge. No close correlation can be found in the daily results, however, because the excess sludge at any time is derived from several days accumulations of primary effluent solids. During the periods shown in the curves, the average of the suspended volatile solids in the primary tank effluent at Wards Island was 82.3 per cent and in

the excess sludge, 75.9 per cent. At Tallmans Island, the average of the volatile solids was 75.1 per cent in the primary effluent and only 58.5 per cent in the excess sludge. The age of the sludge and the reduction of volatile solids by wet combustion seem to be important. Attempts have been made to improve the settling qualities of sludge by the addition of clay or other soils but decreasing the concentration of volatile matter in this way has not been entirely satisfactory.

These relationships explain why it is possible to obtain high concentrations of solids and high sludge index in some plants and not in others. These relationships also emphasize the need for experimental work to aid in the design of new activated sludge plants as well as in the design of sludge disposal facilities, whether they be ships for carrying sludge to sea or vacuum filters, driers or incinerators.

Step Aeration

It is generally recognized that in straight aeration, more oxygen is consumed at the beginning of the tank than toward the end and it is common practice to use coarser plates at the beginning. Other methods have been devised with the purpose of supplying the air according to the needs. One of the newer ways used in the plant at Hackensack, N. J. and in the plant under construction at Muncie, Ind., consists of diffused air aeration in the first part of the aeration period followed by a combination paddle wheel—diffused air system. The amount of air added in the paddle wheel section is relatively small and the paddle wheels are planned to act as floculators.

R. H. Gould, Deputy Commissioner of Public Works for the City of New York, has developed the idea of adding the sewage in regulated amounts at multiple points throughout the course of flow of the returned activated sludge through the tank instead of the usual way of tapering the aeration. He has proposed the name "step aeration" for the process. At Tallmans Island, the return sludge from the final settling tanks is introduced at one end of the aeration tanks. Settled sewage can be added to this at three points as the sludge and added sewage flow through the aeration tanks. As the design is flexible, the amount of sewage added at each point may be varied, the tanks can be operated as normal activated sludge tanks or sludge may be reaerated in the first section.

During the past year the plant has been operated with short aeration periods, both by straight aeration in the usual way and by step aeration. The detention period in the aeration tanks for the past few months has been about 3.5 hours and the air added about 0.4 cu. ft. per gallon of sewage. A comparison of the results of operation by each method is not conclusive because the sewage flow is not yet up to design capacity and because of other factors, such as the intermittent discharge of industrial wastes. However, the Department of Public Works for the City of New York has enough confidence in the process to design the Bowery Bay, Jamaica and 26th Ward plants for step aeration and smaller aeration tanks.

Sludge Concentration

Excess activated sludge is most commonly concentrated by sedimentation with or without agitation. At Tallmans Island, the excess sludge flows to two 24-ft. circular concentration tanks fitted with revolving mechanisms. Chlorine may be added near the center of the tank with the incoming sludge or near the surface in the supernatant liquor. The tanks have been operated with chlorine added at the surface, at the center, at both places simultaneously and with chlorine and lime. For satisfactory thickening, sufficient chlorine must be added to maintain at least 1.0 p.p.m. residual in the overflow. The amount of chlorine required depends upon the condition of the sludge and the monthly averages varied between 38 and 136 pounds per day or about 30 p.p.m. The results indicate that the concentration of solids depends more upon the volatile content of the sludge than upon the place where the chlorine is added. Addition of the chlorine to the center of the tank with the sludge seems to make control of the residual chlorine easier.

Return of the excess sludge to the primary tanks has not been particularly successful at Wards Island. Within a short time the sludge index begins to decrease, probably because of the accumulation of light, slowly settling solids. Somewhat better results are obtained at Tallmans Island where longer detention periods are possible.

Patents

Although patents on equipment and even basic processes of sewage treatment are common, it is rather unusual to find a patent covering the operation of plants. On April 11, 1939, E. B. Mallory was awarded a patent entitled "Process of Controlling the Purification of Sewage." His method of control for the treatment of sewage by the activated sludge process depends upon the relative volumes of the aeration and final settling tanks and upon the maintenance of the amounts and concentrations of suspended solids in the aeration and final tanks in proper relation to the tank volumes. He claims that the amount of aeration, the total amount of suspended solids in the system, and the rate of settling of the suspended solids in the final settling tank must be kept in proper relation to the volumes of the aeration and final settling tanks. Others have taken these factors into consideration in a general way but Mallory claims a precise mathematical relationship for them.

Acknowledgments

The author is indebted to R. H. Gould and W. Donaldson for their helpful suggestions. Acknowledgment is also made to R. Shapiro and H. M. Rath for information and data on the operation of the Tallmans Island Plant.

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DISCUSSION OF DR. EDWARDS' PAPER

BY DON E. BLOODGOOD

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Throughout Dr. Edwards' paper he has referred time and again to the use of the "sludge index" in the control of the operation of an activated sludge plant. He expressed it in a different manner than is given in "Standard Methods of Water Analysis." I know of several plants where other than the standard sludge index is used and each individual has his reasons for his deviation from the standard. It is true that the sludge index is of much value to an operator and due credit should be given to such men as Mohlman, Donaldson, Heisig, Theriault, Rudolfs, and others for their efforts in making the sludge index as usable as it is today.

In my discussions with others about the use of the determination, I have been convinced that they were using the sludge index as a measure of sludge condition and not as a measure of plant condition. If this is true, then any possible changes in procedure which would eliminate variations in index not attributed to sludge condition would seem advisable. I have reference here to the variation in mixed liquor concentration now permissible in the present standard method. I believe that it is a recognized fact that a mixed liquor of 1000 p.p.m. will not settle to the same concentration as a 2000 p.p.m. mixture in the same period of time. This characteristic was noted many years ago at Milwaukee. I have noticed the same peculiarity with Indianapolis sludge and the data presented in Dr. Heukelekian's paper in the July, 1940, issue of THIS JOURNAL bears this out.

The definition of the sludge index as given in "Standard Methods" gives it in a volumetric measurement and as far as I have been able to determine is not comparable with any other data obtained for or used in plant operation. If, however, the sludge index is expressed as the concentration of sludge in the bottom of the cylinders, this can be compared directly with the concentration of the return sludge. This is the method of expression used by Dr. Edwards in his paper.

There is one rule that we have established for activated sludge plant

operation: the return sludge concentration must never be allowed to exceed the sludge index (expressed as per cent solids). This has proved an excellent guide, as following this rule does not permit the retention of sludge in the settling tanks long enough to become damaged.

I believe Heisig has found that for his use he cannot permit the mixed liquor to stand until he has determined the solids, so that he can make his dilution to his standard concentration and so he takes the best estimate he has of the solids of his original sample and makes several dilutions varying them by 100 p.p.m. He then determines the index of all cylinders and after he has obtained the solids he selects the readings of the cylinder which contained his standard concentration. We have never found that the period of standing had any appreciable effect upon the test and so have never gone to the trouble of running the test as he has. We do, however, find it absolutely necessary to correct the mixed liquor concentration.

In the Donaldson index no correction is made for variation in mixed liquor concentration but he has used the per cent solids method of expressing the results which it seems to me is much more desirable.

For those who feel the need of improvement of the sludge index as an indication of sludge condition, I recommend that you try running the test for a month or two with controlled solids and compare the results with those obtained by the method given in "Standard Methods" and decide for yourself if the results obtained by the modified method are not more informative.

Effect of Volatile Matter.—Dr. Edwards discusses to some length the effect of volatile matter upon sludge concentration. It seems to me that his conclusion that high volatile solids cause bulking sludge may be well founded but I am inclined to believe that the effect of the bulking is not the result of the high ratio of volatile to non-volatile but rather a high volatile solids per unit of treatment plant capacity and the treatment plant capacity unit is affected by mixed liquor concentration and detention time in the aerator.

At Indianapolis it is possible to increase the settling quality of the activated sludge by cutting the volume of organic matter being fed to the plant, thus supposedly reducing the amount of volatile matter to be oxidized by wet combustion. It has always seemed to us that there were other factors involved besides actual specific weights of the sludge and filamentous organisms. Whether this effect might be brought about by the swelling of the zooglea masses, I do not know.

Use of chlorine at Indianapolis has not indicated any benefit, as tried on two plants operated as nearly as possible the same.

SLUDGE GAS UTILIZATION *

By Ralph E. Fuhrman

Asst. Supt., Washington, D. C., Sewage Treatment Plant

The utilization of sludge gas is one of the most interesting developments in modern sewage treatment practice. Its popular appeal has helped many a sewage treatment plant to gain attention in the eye of the public it serves as well as to help eliminate potential nuisances of a plant and to lower operating costs. When we consider that energy of 500 to 900 B.t.u. per capita daily is available from sewage sludge in gaseous form, certainly attention to possible uses of this energy is worthwhile. On the other hand, sludge gas is not the only form in which this latent energy in sewage solids may be used and for this reason, only an engineering analysis of each particular problem will indicate the most economical course. My purpose is to review some of the uses of sludge gas as they have developed during the recent years.

Very early in the consideration of the scheme of sewage treatment for a community, a designer is faced with the question of the method of sludge treatment to be adopted. In general it is purely an economical problem, though many elements difficult to evaluate in dollars appear. When digestion is considered as the initial step in sludge treatment, sludge gas enters the picture and is entitled to economical consideration as would any other source of energy. In some cases a scheme of raw sludge incineration is justified while in another it may seem feasible to digest, elutriate and dewater prior to final disposal or incineration of sludge.

Interest in sludge gas utilization has risen greatly in the last fifteen years with the use of controlled sludge digestion obtainable by separate digestion of sludge. Digestion of sewage sludge properly regulated as to reaction and temperature was found to yield gas usually sufficient to maintain the necessary digestion temperatures, heat the plant buildings, and at the same time produce a more easily dewatered sludge in a shorter time. As greater mechanization of sewage treatment processes and correspondingly greater demands for power were made, internal combustion engines operating on sludge gas appeared to supply the need at low cost. Walraven's early work in this phase at Springfield, Illinois, will long stand out as a major contribution. His work gave the use of sludge gas engines the impetus that is still apparent in the field.

Sludge digestion results have been showing increasing yields of sludge gas production. Only a few years ago, a figure of 0.4 cu. ft. per capita daily was considered as average production, but now with good temperature and pH control, yields of 0.6 to 1.5 are common, varying with sewage characteristics and types of treatment.

* Presented at the First Annual Convention of the Sewage Works Federation, Chicago, Ill., Oct. 4, 1940.

Use for Plant Light, Heat and Laboratory

The earliest use of sludge gas, for heating plant buildings, is still probably the most common. Small and large plants alike use the fuel in the many ways to which gaseous fuel is adapted. Likewise, domestic hot water for all cleaning purposes is obtained most conveniently, either by direct gas heaters or indirectly from other heating devices. Sludge gas also finds many uses in the sewage laboratory, as for refrigeration, laboratory burners, water stills, ovens, sterilizers, muffle furnaces, or any place an open flame may be used. An early demonstrative use of sludge gas was to illuminate the plant grounds with old gas street lights, but this use is hardly more popular now than is illumination of city streets by gas.

Use for Motor Vehicle Fuel

Sludge gas has been used resourcefully as a motor fuel to some extent abroad, though this practice is necessarily limited to localities where gasoline is dear. The Johannesburg, South Africa, City Engineer has reported that for motor truck use sludge gas was passed through water under pressure to eliminate the carbon dioxide, and the gas compressed to 5,000 lbs. per sq. in. in a steel cylinder on the truck. Data reported on runs during which carbon dioxide was not removed indicated a consumption of 19 cu. ft. of sludge gas containing 72 percent methane per mile. Since the same trucks gave 9 miles per gallon of gasoline, 171 cu. ft. of gas were equivalent to one gallon of gasoline. The trucks were able to run 131 miles per cylinder full of sludge gas. Similar use in this country has not been practical because of the relatively low cost of gasoline.

Use for Incineration

The use of sludge gas for the incineration of screenings, skimmings, sludge and grit is quite general. Any plant with even a small amount of surplus gas can make use of it to dispose of some of these potential nuisances. Usually, only sufficient gas to start the burning of the materials is necessary, as the fuel value of the solids is quite high. The figure of 1.98 cu. ft. of gas per lb. of screenings has been reported for Dayton, Ohio,[1] and the writer's experience at Springfield, Missouri, indicated about 3 cu. ft. of gas per pound of screenings were sufficient for drained screenings. With gas as fuel, the heat required is from 1,200 to 2,000 B.t.u. per pound of pressed or thoroughly drained screenings. Operation of screenings incinerators is entirely without nuisance when the operating temperatures are high enough. The minimum operating temperature is variably reported as 1,200° F. and up, but with little additional gas that is usually available, an operator can gain some factor of safety by using 1,400° F. as a minimum. The practice of screenings incineration is giving way to some extent to their comminution below the sewage level or their removal, maceration and return to the sewage flow. By this method, the screenings are re-

moved from the sewage with the sludge or scum, depending on specific gravity, and receive further treatment with these solids.

Sludge gas has been employed successfully for the incineration of skimmings in a specially constructed incinerator at the Joint Disposal Plant of the Los Angeles County Sanitation Districts.[2] Gas was necessary only to dry the skimmings, as the volatile solids burn quickly and with a very hot flame when sufficiently dewatered. An operating temperature approximating 2,400° F. was indicated as desirable. At Allentown, Pennsylvania,[3] sludge gas from Imhoff tanks is used successfully to incinerate skimmings from the detritus tanks and screenings from coarse bar screens.

The incineration of grit along with sludge cake and scum with sludge gas as auxiliary fuel is being practiced at Buffalo.[4] The new Buffalo plant is the first to incinerate grit and is now burning the organic matter in 10,000 to 12,000 lb. of grit per day. Before burning, the grit passes through flash driers with the sludge filter cake for moisture evaporation. For the ordinary operation, grit is fed to the drier in the proportion of one part grit to four parts of sludge. At some plants where the sludge is incinerated, partial or total digestion supplies sludge gas for auxiliary fuel. Again, at Buffalo, 850 cu. ft. of sludge gas per ton of sludge filter cake (38.8 per cent solids) is being used.[5] Similar use at the Cleveland Westerly Plant required 769 cu. ft. per ton of sludge filter cake of 34.4 per cent solids.[6]

Also at Auburn, New York, sludge gas is used as auxiliary fuel for sludge incineration. During 1940, on digested plain sedimentation sludge, the amount of gas used in this way has been reported [7] as only 800 cu. ft. per ton of dry solids, though this figure is the result of only one run of 59¼ hours. During 1939, gas used for this purpose was 2,400 cu. ft. per ton of dry solids, a figure comparable to those previously mentioned for Buffalo and Cleveland Westerly, though not necessarily representative at Auburn because a number of incinerator changes have been made. The new Columbus, Ohio, plant uses sludge gas to help incinerate sludge cake.

At Glen Cove, Long Island, sludge gas is used to fire the city refuse adjacent to the plant, and in return the refuse incinerators supply heat for the digestors of the plant. Similar applications of sludge gas use are being made at Herkimer, New York, Ilion, New York, and other cities.

Dover, Delaware, goes a step further to incinerate garbage and city refuse along with screenings and skimmings from the plant with sludge gas as fuel, while Colorado Springs uses gas to fire an incinerator burning the vacuum filtered sludge cake and in addition, the city's garbage.

Power From Gas Engines

By far the most currently popular and spectacular utilization of sludge gas is that of fuel for internal combustion engines. The earliest recorded use of sludge gas for this purpose in the United States is at

Plainfield, New Jersey, where Downes, in 1926, operated three gasoline engines converted for gas use by replacing the carburetor with a mixing valve. The energy produced was used in connection with the sewage treatment plant.[8] The first permanent and large size installation was made at the Sugar Creek Plant in Charlotte, North Carolina, where Platt installed 285 hp. in 1928. Two years later, Rockville Centre, New York, started power production from sludge gas with two engines, one directly connected to a Connersville blower providing 400 to 800 cu. ft. per min. of air and one directly connected to a 25 KVA generator to carry the entire plant load.[9] Both of these engines were equipped for operation on gasoline as an emergency fuel. In 1932, Walraven's first installation at Springfield, Illinois was made of a 180 hp. engine directly connected to a blower furnishing air for activation. This engine was the first in the United States to be designed and constructed for operation on sludge gas. Results were so gratifying that he made a second installation in 1934 of a 157 hp. unit connected to a blower and generator. Since 1934, no year has elapsed without several additions to the list of gas engine installation.

Table I lists typical sludge gas engines in the United States with the approximate time of installation. Though incomplete, this table of installations is given as one fairly representative of installations made to date. The data indicate that, (1) sludge gas engines are still being installed rapidly; (2) that small as well as large plants are using them; and (3) that multiple and additional engine installations are being made, evidently because the engines have given great economy and general satisfaction. The table indicates the size and service of the various engines which were described by several sources. On the basis of horsepower percentage, the division among these uses is given in Table II.

Of the total of 22,170 installed horsepower listed, on a horsepower basis approximately 20 per cent are connected to pumps, 35 per cent to blowers and 45 per cent to generators. Of the actual number of engines, the 135 listed contain 39 or 29 per cent driving pumps, 38 or 28 per cent driving blowers, and 58 or 47 per cent driving generators.

Among the users of gas engines, there seems to be almost complete accord in the satisfaction and economy of their service. In some installations, fear of the consequences of H_2S in the sludge gas has caused much speculation, but actual service has revealed little damage from this cause. Further operation will give desirable information on this point. Exhaust valves are usually specified to be of some corrosion resistant alloy or finish for protection from H_2S at the high exhaust temperatures. Except for this feature, regular gas engine design is applied to sludge gas engines. A common upper limit on H_2S content is about ten grains per 100 cu. ft.

The fuel requirements of sludge gas engines are reported variously because of the different methods of output energy use. Specified consumption of the engines listed in Table I at full load varied from 8,400 B.t.u. per brake hp. hr. for the 1,200 hp. engine at Washington, D. C.,

TABLE I.—*Sludge Gas Engine Installations in the United States*

Year	Location		No. of Units	Horsepower	Driving
1926	Plainfield	New Jersey	2	15	Blower
1928	Charlotte	North Carolina	1	225	Blower
	Charlotte	North Carolina	1	75	Pump
1930	Rockville Centre	New York	1	30	Blower
	San Bernardino	California	1	40	Generator
1932	Rockville Centre	New York	1	60	Blower
	Springfield	Illinois	1	180	Blower
1934	Springfield	Illinois	1	157	Bl. & Gen.
1935	Los Angeles County	California	1	200	Pump
	Cedar Rapids	Iowa	1	210	Generator
	Palo Alto	California	1	40	Generator
	Ontario	California	1	40	Blower
	Madison	Wisconsin	1	230	Blower
	Ann Arbor	Michigan	1	120	Blower
	Peoria	Illinois	1	535	Blower
	Peoria	Illinois	1	300	Blower
	Durham	North Carolina	2	150	Generator
	Greencastle	Indiana	1	50	Blower
	Toledo	Ohio	1	300	Pump
	Toledo	Ohio	1	225	Generator
1936–7	Coney Island	New York	3	300	Generator
	District of Columbia		1	1,200	Generator
	Janesville	Wisconsin	1	30	Generator
	Topeka	Kansas	2	180	Blower
	Richmond	Indiana	1	120	Blower
	Edwardsville	Illinois	1	15	Generator
	Sheboygan	Michigan	2	120	Pump
	Green Bay	Wisconsin	1	120	Generator
	Green Bay	Wisconsin	1	90	Generator
	Fort Atkinson	Wisconsin	1	40	Generator
	LaCrosse	Wisconsin	2	90	Generator
	Hutchinson	Kansas	1	90	Generator
	Elmhurst	Illinois	1	30	Generator
	Kokomo	Indiana	1	45	Generator
	Kewanee	Illinois	1	30	Generator
	Wichita	Kansas	1	70	Pump
	Litchfield	Illinois	1	30	Generator
	Dixon	Illinois	1	30	Generator
	Chicago Heights	Illinois	1	125	Blower
	Atlanta	Georgia			
	Intrenchment Creek		2	120	Generator
	Clayton		2	180	Generator
	Grand Rapids	Michigan	1	50	Generator
	Aurora	Illinois	2	70	Pump
	Madison	Wisconsin	1	230	Generator
	Monroe	Wisconsin	1	30	Generator
1938	New York	New York			
	Tallmans Island		2	800	Blower
			2	450	Blower
			2	350	Pump
			2	150	Pump

TABLE II.—*Continued*

Year	Location		No. of Units	Horsepower	Driving
1938	Columbus	Ohio	3	750	Generator
	Detroit	Michigan	1	364	Generator
	Fort Dodge	Iowa	1	275	Generator
	Lansing	Michigan	1	240	Blower
	Oshkosh	Wisconsin	2	160	Generator
	Albuquerque	New Mexico	1	150	Generator
	Findlay	Ohio	1	90	Blower
	Battle Creek	Michigan	1	50	Pump
	Newcastle	Indiana	1	45	Blower
	Crawfordsville	Indiana	1	44	Blower
	LaPorte	Indiana	1	27	Generator
	Greensboro	South Carolina	2	160	Generator
	Michigan City	Indiana	1	74	Generator
1939–40	Greenville	South Carolina	2	225	Generator
	Springfield	Missouri	2	198	Generator
	Rock Island	Illinois	5	125	Pump
	Rock Island	Illinois	2	75	Pump
	Rock Island	Illinois	1	75	Generator
	Cedar Rapids	Iowa	1	100	Pump
	Belleville	Illinois	1	100	Blower
	Sharon	Pennsylvania	2	80	Generator
	Butler	Pennsylvania	1	80	Generator
	Wausau	Wisconsin	1	75	Generator
	Wausau	Wisconsin	1	50	Generator
	Wausau	Wisconsin	1	50	Pump
	Pueblo	Colorado	3	75	Pump
	Manitowoc	Wisconsin	1	75	Pump
	Manitowoc	Wisconsin	1	35	Pump
	Davenport	Iowa	1	75	Generator
	Davenport	Iowa	1	75	Pump
	Kenosha	Wisconsin	2	75	Pump
	Stevens Point	Wisconsin	1	75	Generator
	Marion	Indiana	2	75	Blower
	Marion	Indiana	1	50	Pump
	Ithaca	New York	1	50	Pump
	Lake Charles	Louisiana	1	50	Blower
	Carlsbad	New Mexico	2	50	Pump
	Metairie	Louisiana	1	50	Blower
	Two Rivers	Wisconsin	1	43	Blower
	Two Rivers	Wisconsin	1	40	Pump
	Escanaba	Michigan	1	40	Generator
	Shawano	Wisconsin	1	35	Generator
	Litchfield	Illinois	1	30	Generator
	Monroe	Michigan	1	25	Pump
	Gary	Indiana	3	175	Pump
	Gary	Indiana	2	300	Blower
	Cleveland	Ohio	2	390	Blower
	Fort Wayne	Indiana	1	450	Blower
	Adrian	Michigan	1	45	Blower
	Peru	Indiana	1	45	Blower
	Pontiac	Michigan	1	150	Blower

TABLE II.—*Distribution of Uses of Engines Listed in Table I According to Horsepower*

Year	Pump	Blower	Generator	Total	Cumulative Total
1926		30		30	30
1928	75	225		300	330
1930		30	40	70	400
1932		240		240	640
1934		79	78	157	797
1935	500	1,275	775	2,550	3,347
1936–7	450	605	3,740	4,795	8,142
1938	1,050	2,919	3,780	7,749	15,891
1939–40	2,275	2,463	1,541	6,279	22,170
Total Horsepower....	4,350	7,866	9,954	22,170	
Percent of Total.....	19.6	35.5	44.9	100.0	

to 14,500 B.t.u. per brake hp. hr. for the 45 hp. engine at Ontario, California. The most common value of the guaranteed fuel consumption at full load is 10,000 B.t.u. per brake hp. hour. Nearly all of the recently installed engines have been specified for gas of 600 B.t.u. per cu. ft., though this figure ranges from 550 to 900 B.t.u. per cu. ft.

Continued use and expansion of use of sludge gas engines is bound to continue as long as electrical energy rates do not drop sharply. On some installations, the investment is saved in electrical energy costs within two or three years, but the larger installations take longer because of lower rates prevalent in the population centers. In some rare cases, use of sludge gas engines has been discontinued because of noise or excessive cost of engine operation and maintenance.

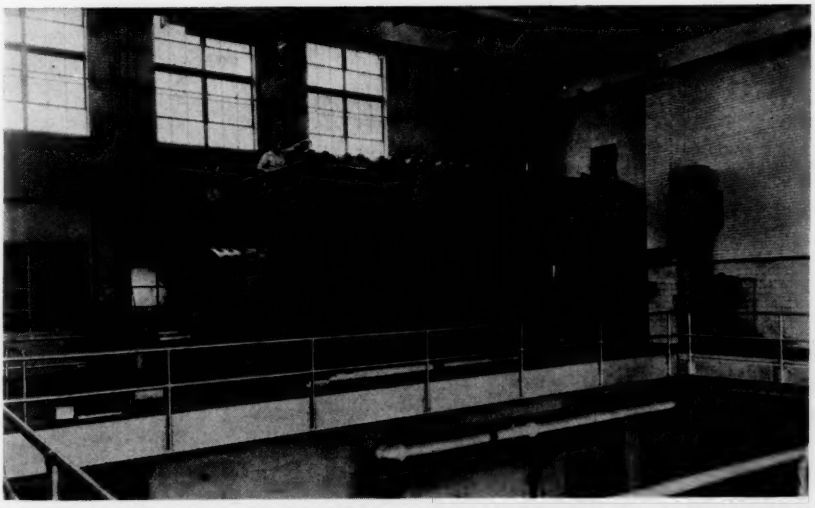

FIG. 1.—1200 H.P. sludge gas engine, District of Columbia Sewage Treatment Plant. Engine manufactured by The Rathbun-Jones Engineering Company, Toledo, Ohio.

At the District of Columbia plant, a recent proposal has been made to add to the single 1,200 hp. engine another sludge gas engine of 1,500 hp., a Diesel of 750 hp. and disconnect the Utility standby. The new units, as the first, would be directly connected to generators. With these facilities, the plant will save standby and demand charges and be entirely independent of outside sources of energy. Estimates indicate that savings effected by the engine now in service are $13,000 annually, while with the completely independent plant, the estimated annual cost of electrical energy is $23,000 less than the cost of electrical energy if no power were produced from sludge gas at the plant. These figures include all fixed and operating charges.

During the 1939 fiscal year, which was the first operating year of the Washington, D. C. Plant, the 1,200 hp. engine operated over 95 per cent of the time and supplied over 95 per cent of the total electrical energy requirements of the entire plant. During the following year, interruption of plant operation because of outfall sewer repairs made similar figures for the 1940 fiscal year meaningless. No difficulties from hydrogen sulfide corrosion have arisen in the 15,000 hours of service that this unit has had. Under good conditions of operation, recoveries of the energy going into the engine as sludge gas are, as power (electrical energy at the bus) 23 per cent, as jacket water (to digestors) 30 per cent, as steam from exhaust heat 12 per cent, losses (both heat and electrical) 35 per cent. These results are in accord with operating reports of other plants.

Heating Sludge Digestion Tanks

Since the value of sludge gas as a source of heat was first appreciated, gas has been used to maintain digestion tank temperatures at an active level. At first heat was obtained by direct fired gas boilers, but as gas engines have come into service, the heat ordinarily wasted in jacket water and exhaust has been used to heat the digestors. Since gas boiler efficiencies are 60 to 75 or 80 per cent, a gas engine can compete on a heat basis because 50 per cent of the gas fuel heat content is recoverable through its exhaust gas, jacket water, and radiation.

Plainfield, New Jersey, again led with the initial installation of sludge gas fired digestion heating in 1926.[10] Though this application was to a plain earthen tank with a floating wooden cover and a coil of iron pipe for the heating water, the benefits were so pronounced that other cities adopted the practice almost immediately. During 1927, Antigo, Wisconsin, built a plant including a covered digestion tank with heating coils, gas-fired boilers, and circulating pump for the heated water.

The same year and the following found many plants underway incorporating gas-fired heating facilities. Design of sludge digestion tanks now ordinarily includes these features or at least provision for their addition at a later date. The permanent omission of heating equipment seems justified only in the southern plants, where natural

temperatures are high enough for good sludge digestion. Where a gas engine is installed, waste heat from the engine usually supplies all ordinary heating loads, while an auxiliary gas or combination gas-oil fired boiler may supply heat for peak loads, when the engine is not operating, or when the gas supply may not be available.

Gas fired hot water boilers are available in sizes requiring about 60 and up cu. ft. of gas per hour. At 60 cu. ft. per hr. and 1.0 cu. ft. of gas per capita daily, a population of 1,440 would yield sufficient gas for the boiler. Whether or not such a boiler would be adequate for the plant is a question that only individual analysis of heat requirements can answer, but such an analysis is worthwhile even in the case of small plants. In plants where hydrogen sulfide is always present in the gas, some corrosion occurs on the boiler surfaces when a hot water boiler is used because of the low operating temperatures. In steam boilers, with temperature somewhat higher, the corrosion is reduced greatly, but in such an installation, a heat exchanger is necessary to heat the water to be circulated in the digestion tanks for heat.

Hazards in Sludge Gas Handling

Mention of the utilization of sludge gas is incomplete without some consideration of the hazards and dangers involved in handling the gas. Our journals frequently put before us forceful accounts of damaging explosions at sewage treatment plants. Such explosions certainly give the undeniable truth of the great power the gas holds. It may be too easy for an operator to read the reports and say 'it can't happen here' rather than keep a constant check on the features of his plant and operating methods which make for safety in gas handling.

All gas explosions—even those within the combustion chambers of our gas engines—have one thing in common. That is a combination of an explosive mixture of gas with air *and* some means of ignition, as an electrical or mechanical spark or an open flame. Either the explosive mixture or ignition may occur alone without consequence, but when the combination prevails, an explosion is no matter of chance, but a certainty. When we realize that explosive mixtures of sludge gas and air in the range of 5 per cent to 15 per cent sludge gas may be explosive, it is clear that safe limits of sludge gas in air must be two per cent or less.

Prevention is necessarily built up by eliminating possibilities of the dangerous combination of an explosive mixture and a means of ignition. One of the most effective and commonly applied methods of protection is the complete building separation, as far as possible, of all gas control equipment, as drip tanks, flame traps, pressure regulators, meters, and valves. With these appurtenances, leakage is certain to occur at joints and stuffing boxes, and the chance for explosive mixtures within the space is great. However, with an explosion proof electrical installation and separation from the regular operation controls of the plant, the danger of automatic ignition is eliminated, but even then

great care by the operators in the use of proper tools is necessary. As a step beyond "No smoking, matches or open lights," the use of a non-sparking floor surface or covering in the gas control room appears very desirable to eliminate innocent sparks from steel shoe plates or nails or an improper tool.

Any enclosed space where sludge gas may find its way, whether it be normally or abnormally, must be ventilated not only for the sake of explosion protection but for protection of plant operators against asphyxia. Asphyxia may result from dangerous concentrations of methane, carbon dioxide, hydrogen sulfide or by a mixture of any gas with air that reduces the oxygen content of the mixture to less than 12 per cent. This limit must be remembered so that no one will wear a gas mask in an atmosphere deficient in oxygen, expecting it to give complete protection for this use, as only an outside source of oxygen as a self-contained oxygen breathing apparatus or an air hose mask is sufficient.

As protection against ignitable mixtures of sludge gas in enclosed spaces, a relatively new tool is now available. It is a combustible gas alarm which continuously samples the atmosphere and gives any desired electrical signal at a predetermined concentration, usually expressed in per cent of the lower explosive limit of the gas. While the installation of such an instrument may not be justified at all plants, it offers a definite protection to plants large enough to make the investment. Such an alarm has been installed at the District of Columbia plant in the digestion gallery. Though the gallery contains no gas piping, the possibilities of gas release by pump venting and from lines which would contain gas under abnormal operating conditions was considered great enough to justify the installation.

For safety, operators of sludge digestion tanks should use extreme care in extending gas piping and control equipment. Such additions must be made cautiously and on the best advice obtainable, lest some protective feature be eliminated or a new hazard created.

Conclusion

Though sewage sludge gas had its first recorded use for lighting at the Exeter, England, plant in 1895 and the first use for power at Matunga, India, in 1902,[10] the progress evident now in its use is largely the result of advancements made in the last fifteen years. What the future holds for a practice so new is a matter of conjecture, but many features of current practice will probably survive. Power production as we know it now from sludge gas is likely to stay a long time, though competition with burning of raw solids for steam generation is a possibility.

Disposal of garbage with sewage may enter the picture, doubling gas yields from sludge digestion to further increase the economies of sludge gas utilization. Our present noisy reciprocating sludge gas engines may yield to the smooth running gas turbine when the turbine is developed to a point of equal thermal efficiency. Several gas tur-

bines are in operation in this country and abroad now,[11, 12] and developmental work to step up their efficiency is progressing. If their use becomes a reality, our current power producers may be superseded by sleek gas turbines, just as compact steam turbines are superseding the faithful reciprocating steam engines.

The use of sludge gas has become a well established part of modern sewage treatment practice. New uses for sludge gas are certain to appear, as present uses are certain to be improved. Entirely new chemical uses of the principal constituents—methane and carbon dioxide—may appear as the chemical market rises in the coming years.

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DUAL DISPOSAL—WHERE DOES IT STAND TODAY?*

By Edward J. Cleary

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The title of my paper, "Dual Disposal—Where Does it Stand Today?" propounds a question concerning which there is lively controversy. My role in discussing this subject is that of an impartial observer. Accordingly, I will endeavor to lay before you such information as is available, and then touch upon some questions which may have arisen in your mind as they have in mine.

The story of dual disposal begins in 1923 at Lebanon, Pa. Here was originated the idea of using sewers for the transportation of ground garbage to a sewage treatment plant for disposal. After a short period of experimental operation the scheme was abandoned, and for the next decade little or nothing was heard of combined garbage-sewage disposal. The next chapter of the story begins in 1933 when active research was undertaken, notably at Baltimore, Indianapolis, and the University of Illinois. Contemporary with this period of research was the adoption of garbage grinding for disposal into sewers by St. Louis, and the country-wide introduction of a home grinder unit. Historians will also note that throughout this period the voice of one man—Morris Cohn of Schenectady—was a constant stimulus in urging further investigation of this process of disposal, for the home as well as the municipality.

The third chapter of dual disposal is now in the making. It will deal with experiences in operating municipal treatment plants designed to handle both garbage and sewage. The pioneer plant at Lansing, Mich., already has seen fourteen months of operation. A grinder installation has been made at Findlay, Ohio; Goshen, N. Y. began operation in August, and new plants are nearing completion at Rock Island, Ill., Gary, Ind. and at Marion, Ind. A year from now we should have some of the answers to the questions asked today.

Resumé of Research Findings

Addressing themselves to the question, "Can sewage treatment processes handle garbage solids?" research workers have come to the general conclusion that it can be done. However, the limits of loading have not been conclusively defined, and there are but scanty data relative to the cost of handling garbage through sewage purification devices.

Concerning the effect of garbage additions on specific treatment devices the following resumé of experimental findings reveals many items of practical significance:

* Presented at the First Annual Convention of the Sewage Works Federation, Chicago, Ill., Oct. 3, 1940.

Screens: Baltimore experiences indicated that bar rack screenings were increased by 50 per cent during the summer period when corn husks were ground and stringy fibers clung to the screens. More thorough grinding and *adequate* screening facilities are indicated to cope with this condition.

Grit Chambers: Indianapolis investigations showed that the grit separated from garbage amounted to 8 per cent of the total garbage solids. Further, since the grit was high in organic content—over 50 per cent—adequate grit washing devices would appear to be essential in a dual disposal plant. Fine grinding, incidentally, is said to reduce the organic content of grit.

Primary Settling Tanks: All laboratory and full scale experimental work has indicated that mixtures of garbage and sewage solids settle as well as, if not better than sewage solids alone. However, indications are that there will be a considerable increase in floating solids and grease formation. The increase in primary tank sludge due to the addition of garbage ranged from 17 to 28 per cent at Indianapolis.

As might be expected, the B.O.D. of the primary tank effluent is increased when garbage solids are added to the sewage flow. In this connection we should recall another significant finding made at Indianapolis, namely, that garbage suspended solids amounted to 75 per cent of the total garbage solids; in other words, one-quarter of the solids in a batch of garbage passed out of the settling tank in the form of colloidal and dissolved constituents of the effluent.

On secondary oxidation devices these constituents would materially increase the loading. How much? Investigators are at variance in this regard. Some say the B.O.D. will be increased from 11 to 20 per cent, and in one instance the results indicate that it may range from 25 to 100 per cent, and will average about 43 per cent.

Oxidation Devices: Based on indicated increases in B.O.D., in primary tank effluent, the need is seen for larger capacity in secondary treatment units. Little data are available, however, except for Calvert's observation that at Indianapolis the activated-sludge plant would require an increase in plant capacity and power of some 3 per cent, and Tolman's conclusion that operating costs for air alone would be increased by about 11 per cent.

Chemical Treatment: Experimental work by Rudolfs and Ingols, using a mixture containing equal quantities of sewage and garbage suspended solids, shows that such mixtures require more coagulants than sewage alone, but not in proportion to the added garbage solids.

Garbage and Sewage Solids Digestion

Turning now to the important matter of digesting mixtures of garbage and sewage solids, it is to be noted that this phase of dual disposal has been quite thoroughly studied both in the laboratory and on

a plant scale basis. All conclusions point to the fact that such mixtures will digest readily in the usual proportion of garbage and sewage solids emanating from a community.

No difficulty was experienced at Baltimore, for instance, in digesting equal volumes of raw sludge and garbage, provided sufficient seeding material was used. Daily loadings of the mixture in amounts as great as 5 per cent of the initial volatile solids in the seed sludge were possible.

The results obtained from some thirteen tests by different investigators may be summarized as follows:

(1) Digestion could be carried on with mixtures of garbage and sludge in which the ratio varied from 1 part garbage and 3.1 parts sludge up to 1 part garbage and 0.7 parts sludge (on a volatile matter basis).

(2) Digestion periods varied from 4 to 64 days. Charging rates were from 0.035 to 0.422 lb. of volatile matter per cu. ft. of digestion capacity.

(3) Gas production per lb. of volatile solids added varied from 8 to 13 cu. ft.

(4) Methane content of the gas varied between the limits of 57 and 65 per cent.

Experimental work at several places indicates that digester capacity requirements increase in direct proportion to the increase in volatile solids. This means that if garbage volatile solids are added equivalent in amount to the sewage volatile solids already present, the digester should be increased in size by 100 per cent.

After digestion, of course, comes the matter of ultimate disposal. Research findings indicate that the digested mixture of garbage and sewage sludge drains readily and will dry without nuisance on sand beds. It is also stated that the digested mixture can be dewatered on vacuum filters.

Plant Operating Experiences

Records are available of a year's operating experience at the pioneer sewage-garbage disposal plant at Lansing, Mich. These results, made available by G. F. Wyllie, superintendent, and Messrs. Shoecraft, Drury and McNamee, consulting engineers, constitute one of the most important contributions to dual disposal practice.

At Lansing, a city of 75,000, all of the garbage, averaging 21 tons a day, is ground and deposited in the heated sludge digestion tanks. Each tank receives also plain sedimentation and activated sludge from the sewage treatment plant, which now handles a flow of 7.5 m.g.d.

Briefly stated, here are some of the important findings:

1. Sewage and garbage solids digest readily and thoroughly. But under present operating conditions a serious problem has arisen in connection with the quality of supernatant liquor. Prior to the addition of garbage the digester supernatant contained less than 0.5 per

cent solids, but after garbage was added the supernatant contained from 2 to 2.4 per cent solids. The return of this liquor eventually overloaded the treatment works and caused bulking of the activated sludge. It is believed that stage operation of the digesters will result in supernatant of better quality.

The mixture of raw solids pumped to the digesters has averaged 1.0 part of garbage to 1.36 parts of sludge, on a volatile solids basis. The capacity of the digester is 300,000 cu. ft. which provides 4 cu. ft. per capita on the basis of present connected population. No trouble is reported in dewatering the sludge on a vacuum filter.

2. Gas production, after garbage was added, increased by 230 per cent. Gas production per pound of volatile solids added averages 11.3 cu. ft. Following the addition of garbage the carbon dioxide content of the gas increased about 6 per cent—from 30 to 36 per cent—but the higher content apparently does not affect the operation of the Lansing gas engine.

3. Bones, egg shells and fruit pits are the cause of serious clogging in waste sludge pipes leading from the digester. Because these finely ground materials have a specific gravity greater than sludge, they settle out rapidly in the digesters. To correct this condition, which is aggravated by the presence of bottle caps, plans are being made to provide a special grit chamber into which the mixture of raw sludge and ground garbage will be passed before entering the digester.

4. Ground bone and fruit pits also cause clogging of sludge pumps, but this has been corrected in large part by providing additional clearance on the ball check valves.

Questions to be Answered

Having presented a resumé of experimental and full scale operating results, I now come to the query—what is the status of dual disposal today?

Anyone attempting to make such an evaluation must keep in mind two fundamental questions with which we approach the application of all new processes. These are:

1. Will it work?
2. How much does it cost?

To the first question a number of engineers would reply with an emphatic yes. To support this conclusion are the results achieved at Lansing where all the garbage for the city of 75,000 is handled at the sewage treatment plant. Results of many laboratory and field investigations also indicate that various combinations of the mixed materials digest and are amenable to treatment.

Other engineers want more data from plant scale operation before they will admit that dual disposal is practical. Quite logically they raise questions like these:

1. Where should garbage be added for most efficient results—directly to the digesters, at the plant influent, or into the sewer system above the plant?

2. If garbage is added to the incoming sewage, can the additional load be carried by existing treatment devices without major modification?

3. How should garbage be added—continuously, on a batch basis, or proportional to the sewage flow?

Even if there should be unanimity of opinion on the desirability and workability of the process there still remains the vital question, "How much does it cost?" Regarding this, I think I am safe in saying that no one is at present in a position to make a fair appraisal of dual disposal. It is true that some estimates of cost have been made. For example, Calvert at Indianapolis arrived at a figure of 57 cents per ton of green garbage including increased sewage plant cost, interest, depreciation and operation of the grinding station, but not including digestion (sludge is lagooned at this plant). Keefer at Baltimore calculates that the cost would be $3.20 a ton, of which sludge digestion and drying on sand beds accounts for $2.81. However, this figure does not include any allowance for handling additional screenings, grit, grease or extra loading on treatment devices.

Furthermore, it appears that an important requirement in dual disposal practice is to secure thorough separation of garbage from other materials, as well as to remove bones. No one has estimated the cost of this extra operation.

But suppose we did have accurate knowledge of what it would cost to process garbage in a sewage treatment plant, there still remain two auxiliary factors, consideration of which will have a profound effect on a cost analysis of dual disposal. One of these factors concerns the utilization of the extra gas produced by garbage. The value of this by-product cannot be ignored when we learn that its use is estimated to result in annual power savings of about $9,000 at Lansing and a minimum of $13,000 at Gary.

L. R. Howson of Alvord, Burdick and Howson, Chicago, consultants on the Gary installation, puts it this way: "The value of the additional gas which it is estimated will be secured from the garbage grinding will be equivalent to approximately 8 per cent return on the cost of the garbage grinding and digestion capacity plant addition."

The second factor calling for consideration in a cost evaluation concerns rubbish disposal. If garbage is handled at the sewage treatment works, what will it cost to provide separate and adequate disposal facilities for community rubbish and ashes? Quite possibly the cost for these additional facilities in some communities might nullify any savings achieved by the utilization of by-product gas.

I think it is proper to conclude that the all-important question of the economics of dual disposal cannot be answered now or for some time to come. Not until data are available from full-scale operating installations can definite knowledge on costs be acquired.

Summary

On the basis of available data, the present status of dual disposal would appear to be as follows:

1. Research results give every indication of the workability of dual disposal. But conclusions concerning the practicability of combined garbage-sewage treatment on a large scale must be considered as tentative and subject to modifications revealed by actual plant experiences. There is still much to be investigated concerning the effect of garbage on treatment processes, capacity requirements, and quality of effluents.

2. Practically nothing is known about the cost of handling garbage through a sewage treatment works.

3. Even if we had the complete answers as to the workability and cost of the process, the acceptance of dual disposal by a community must be made contingent upon a careful economic study of the entire problem of refuse disposal. Disposal of garbage is only one element of this problem, leaving for further consideration the disposal of rubbish and ashes. The latter constituents may account for 75 per cent by weight of the total community waste. Incidentally, the removal of garbage from refuse should complicate incinerator operation because of the high temperatures produced when rubbish alone is burned.

In conclusion, may I urge that we remain open-minded about dual disposal, realizing that much progress has been made in the last seven years toward clearer conceptions of the practice of combined garbage-sewage treatment. And we must also recognize that these conceptions have crystallized into convictions resulting in the adoption of the process by several cities. It is to the builders and operators of these pioneer installations that we must look for the answers to our questions.

DISCUSSION OF "DUAL DISPOSAL, WHERE DOES IT STAND TODAY?"

By L. R. Howson

Consulting Engineer, Chicago, Ill.

We are indebted to Mr. Cleary for his concise yet comprehensive presentation of past accomplishments and deficiencies, present status and questions still to be answered regarding "dual disposal."

Dual disposal, like all other engineering problems, ultimately simmers down to a consideration of economics. There is no method or combination of methods of municipal waste treatment generally applicable to all conditions. Each decision, therefore, must be based upon a careful analysis of the requirements and a comparative study of the various practicable means of meeting them, each estimated as to cost, and all evaluated on a common basis of accomplishment and annual cost. This discussion of Mr. Cleary's paper will apply its reasoning to the Gary installation.

Among the conditions favorable to "dual disposal" at Gary were:

1. The city already had an incinerator capable of handling all of the rubbish but entirely inadequate to handle garbage with the rubbish.
2. Dual disposal made it possible to utilize the existing incinerator for rubbish. With any other means of disposal it would have been necessary to have scrapped the existing incinerator.
3. Dual disposal when credited with the value of the additional gas for power was about $12,000 per year lower in annual cost than incineration with heat recovery, and approximately $19,000 per year cheaper than incineration alone. In first cost, grinding and digestion was only about one-half as costly as incineration with heat recovery.

Admittedly "dual disposal" on a municipal plant scale is still more or less in the pioneering stage. As such, it should be recognized that the early installations will be modified as time passes and a greater background of experience becomes available for guidance.

One of the best means of avoiding pitfalls in pioneer work is to design liberally; just as with activated sludge, early designs provided in excess of 1 cu. ft. of air per gallon for ordinary strength sewages, but the plants were later operated satisfactorily with from 0.4 to 0.7 cu. ft. per gallon, and just as with trickling filters the early loadings of B.O.D. per acre foot were very materially lower than those now known to be practicable, so is it desirable to provide liberal factors of safety or, if you please, factors of ignorance in the design of "dual disposal" systems at this time.

For illustration, at Gary, sludge digestion capacity has been provided in the amount of approximately 9 cu. ft. per capita based on the present population, and 6 cu. ft. per capita based on the design population, figures materially greater than have been used in earlier plants where some digestion difficulties have been experienced. In determining the digester capacity for dual disposal the designer must provide for the extreme fluctuations in garbage solids which reach a maximum during the cantaloupe, sweet corn, and watermelon season. The ratio of peak to average monthly solids may be twice as great with garbage as sewage and this must necessarily be reflected in digester capacity.

Similarly, the area of the digestion tanks has been made large and the depth relatively shallow in order to minimize the effect of the violent gassing. At Gary the surface area of the digesters is over 50,000 sq. ft. At 2.5 cu. ft. of gas per capita, the gas collected per square foot of tank will be only 6 cu. ft. per 24 hours. It is hoped that this liberal area will reduce the trouble experienced elsewhere due to "boiling" and the resulting excessive solids in the supernatant liquor.

It is further the writer's opinion that the provision of duplicate or multiple facilities is more than usually essential in pioneer installations. At Gary there are two garbage grinders, five sewage comminu-

tors, two mechanically cleaned grit chambers, four clarifiers, and eight digesters.

Based upon the observation of experience elsewhere, it is believed particularly important with garbage grinding to have grit removal facilities prior to passage of the sewage and garbage to parts of the plant with restricted pipe openings. The easiest way to accomplish this is to locate the grinder along the sewer above the treatment plant. At Gary the garbage grinding installation is located on the sewage treatment plant site immediately adjoining the main intercepter and about 300 ft. upstream from the comminutors.

In air equipment the Gary installation is also very liberal. There are three electric motor driven centrifugal units and two gas-engine driven displacement units in sizes such that deliveries of 5,000, 7,000, 9,000, 12,000, 14,000, 16,000, 19,000, 21,000, 26,000, 28,000, 30,000, and 35,000 cu. ft, of air per minute are practicable. Up to 14,000 cu. ft. of this capacity can be supplied by the gas-engine driven units. The total capacity is equivalent to 1.25 cu. ft. of air per gallon of sewage on the design basis, of which 0.5 cu. ft. per gallon is gas-engine driven. This relatively large air installation is to permit as great utilization of the gas as possible and at the same time to protect against the contingency of complete electric operation if necessary. Gas storage of 200,000 cu. ft. is provided to equalize variations in gas production rates due to irregular addition of garbage solids. It is estimated that the increased use of air due to the addition of garbage solids will be some 15 per cent, more or less.

Unfortunately operating data at Gary are not yet available. The sewage treatment plant has just gone into operation. Aeration was started about two weeks ago. Garbage grinding has not yet started. It is probable that initially only about 15 tons a day of garbage from the central business district will be handled at this plant. That will gradually be extended to take in the entire city, which it is estimated will produce from 30 to 35 tons per day.

As Mr. Cleary has pointed out "dual disposal" has been born and is being carefully watched during the adolescent stage. It is now beginning to speak for itself through operating records and eventually there will emerge more definite limits of its economic practicability. The experiences of men like W. W. Mathews at Gary and G. F. Wyllie at Lansing will be well worth watching.

PROGRESS IN THE CONDITIONING OF SEWAGE SLUDGE FOR DEWATERING*

By Frank Woodbury Jones

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Sewage sludge, like some investment stocks, is hard to dispose of because of the water. Water may be legislated out of stocks and bonds, but to find reliable, practicable and economical methods whereby sewage solids may be separated from their moisture effectively and without creating a nuisance, has been a consummation devoutly to be wished by all sanitation engineers and chemists since the advent of sewage treatment. Rideal voices the experience of every sewage plant operator when he states: "The great difficulty in dealing with sewage sludge is its bulk, containing as it does 92 to 98 per cent water."

When the title of this paper was assigned, in all probability the basic thought in mind was a discussion of the addition of chemicals prior to vacuum filtration. Within the past few years, the technical literature has been well supplied with articles on conditioning and dewatering by vacuum filtration, and it appears somewhat futile to present another dissertation on that subject alone, particularly since some of the newer installations are still inoperative. Consequently, we shall review, briefly, past and present experiences in the dewatering of sewage sludge, with particular emphasis on the preparation for effective dewatering by mechanical means.

Early Methods of Sludge Dewatering

The early text books on sewage disposal mentioned as methods for dewatering prior to final disposal: drying in air; drying in presses; drying by centrifugal machine; and spreading on land. Means for disposal without dewatering included: burying in trenches; filling in low land; and dumping at sea. Besides these, many wishful processes were suggested but little used, such as: "drying over a fire"; drying for fertilizer; electrolytic disintegration; and destructive distillation. The pioneer writers also mentioned the possibility of dewatering in stages by use of concentration tanks and special digestion chambers.

Types of Sewage Sludge

At the turn of the century, most of the sewage sludge was produced in either plain sedimentation or chemical precipitation tanks. Since that time, and particularly in the last fifteen years, there has been an amazing increase in the number of sewage treatment plants. Coincident have been innovations in both processes and equipment, with the result that there is today in service, an impressive array of sewage

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works of all sizes and description, from very small to mammoth, producing a variety of sludges, all of which, in keeping with modern thought and trend, must be disposed of permanently and without nuisance.

Among the many types of sludges found in modern sewage treatment works may be mentioned the following, which, as will be seen, still include the sludges of former days:

(*a*) Fresh sludge from plain sedimentation of raw sewage.
(*b*) Fresh sludge from chemical precipitation of raw sewage.
(*c*) Fresh sludge from the activated sludge process.
(*d*) Fresh humus sludge from trickling filter effluents.
(*e*) Fresh sludge from the biochemical process.
(*f*) Fresh sludge mixture from plain sedimentation and activated sludge process.
(*g*) Fresh sludge mixture from plain sedimentation and biochemical process.
(*h*) Plain sedimentation sludge digested in separate tanks.
(*i*) Chemical precipitation sludge digested in separate tanks.
(*j*) Mixed activated and plain sedimentation sludge digested in separate tanks.
(*k*) Raw sludge digested in Imhoff tanks.
(*l*) Mixture of humus and raw sludge digested in Imhoff tanks.
(*m*) Partially digested Imhoff tank sludge, digested in separate tanks.

Present-day Methods of Dewatering

The problem of dewatering sludge today is no different from that of yesterday. We continue to use some of the older methods; dry bones of former attempts and abandonments have been brought to life; and new processes have been devised. The end sought is the same, but in common with practically all current human endeavor in its attempt to go forward, we have streamlined the equipment, and speeded up the processes, so that we reach the goal by auto express, as it were, instead of by mule team freight. Illustrative of this change, the old hand-propelled squeegee has developed into the mechanically driven straight-line and circular sludge collector; the "prepared areas" of early days have been refined to the glass-covered sludge drying beds with rigid specifications as to underdrains and filtering media; and the open smelly digestion tanks have been transformed into heated castles, with all manner of appointments designed to cope with the varying demands of flexible operation.

Centrifuging has had a revival in several demonstration units within the past few years. Drying over a fire appears to have gone beyond the dream stage, and preparation for use as a fertilizer is an accepted procedure. Lately, reference was made in the literature to a method of preparing sludge for dewatering by freezing. So, with fire as one extreme and cold as the other, if we are to believe the poet Milton, we have ample justification for the oft repeated plaint that sludge disposal is hell.

Advent of Vacuum Filtration

Sewage sludge, when first deposited, is highly putrefactive, and much of the early grief with sludge dewatering arose because of this fact. The first effective measure in preparation for effective dewatering came with digestion. Viscous fresh solids, always likely to produce odor when exposed, are greatly transformed by proper digestion into black humus-like, somewhat granular substances relatively free from odor and separable from their water by drainage. Such sludge could be dewatered to a handleable cake on sand drying beds without offense. When the sand beds were full, it could be pumped to the ubiquitous nearby hollow, where, if sufficiently hidden, not even the visiting inspector would discover its illicit resting place. The sand bed is still in general use, and this method of dewatering will continue, but its usefulness is confined to dewatering digested sludge.

Attempts to use sand beds for other types of sludge, and in cases where digestion did not effectively prepare the sludge for dewatering, have not been generally successful, even when chemicals have been added to destroy odor and to accelerate drainage. Chemicals used were usually alum, ferric chloride, or chlorinated copperas.

The need for a suitable substitute for the old reliable sand bed and the much maligned lagoon was accentuated by the advent of activated sludge, which has low solids content and is very putrefactive. This fact, together with the growing variety of sludges, and the desire to dewater some of these without digestion, led the sanitation engineer into the mining industry, from which he has taken the vacuum filter and adapted it to the dewatering of sewage sludge. This method has developed rapidly from the first practical installation of Milwaukee for dewatering activated sludge, less than twenty years ago, to the present, when there are certainly more than two hundred units of this type, almost all installed since 1935.

Vacuum filtration, especially on large installations, can fulfill the requirements of effective dewatering, since it functions acceptably free from odor, quickly, and at reasonable expense. Consequently, Dr. Mohlman perhaps is justified, when he states: "The vacuum filter still remains supreme for dewatering sludge." This paper, intended solely to be thought provoking, rather than informative, will continue by discussing some of the factors which have been developed in the preparation or conditioning of sludges for reduction in moisture by this method.

Conditioning for Vacuum Filtration

General.—In general, it may be said that all types of sludge can be dewatered by vacuum filtration if properly conditioned or prepared. It should be recognized, however, that certain industrial wastes or excessive quantities of grease and oil might create serious problems. Some of the factors involved in this preparation are digestion, concentration, uniformity, elutriation, chemicals, and mixing.

Digestion.—Digestion of fresh solids must be regarded as one of

the means for preparing sludge for vacuum filtration. As recent as eight years ago, it was regarded as impracticable to condition and filter digested sludge, but that day has passed. Digestion decreases the weight of solids to be handled by some 30 to 40 per cent; it provides a more uniform sludge as to composition; it is less likely to produce odor; and it is amenable to washing or elutriation and a possible savings in overall cost.

Whether or not to digest, is still an open question, in which controlling factors such as location of works, size of installation, type of sludge, storage of wet sludge, control of nuisance, decrease in weight of solids to be filtered, temperatures, grease content, concentration of solids, utilization of gas, disposal of the filter cake, and cost both capital and operating, must all be properly evaluated. It may be stated, however, that where filter cake is to be disposed of by dumping on poorly isolated areas, it is advisable that digestion be a part of the preparation for dewatering.

Concentration.—A most important factor in the conditioning of sludge is proper concentration, and much progress has been made in evaluating its effects. In the early days, when only fresh solids were conditioned and filtered, a concentration of 5 to 6 per cent was regarded as the upper limit. Recent experience has demonstrated that almost any reasonable concentration of either digested or undigested sludge can be conditioned and filtered. The upper practical limit appears to be around 10 per cent, although there are records of dewatering heavier sludges. In general, the higher the concentration of solids, the greater the yield in pounds per square foot per hour, and the less the chemical dosage for coagulation.

A corollary to concentration is the uniformity or perhaps better homogeneity of the sludge to be filtered. Dosages can be adjusted to accommodate varying concentrations, but if these fluctuations come too rapidly, there is bound to be ineffective performance either in improper use of chemicals or in the production of an inferior cake.

Another corollary to concentration and uniformity, is the need for storage between settling tanks and inlet to the conditioning tanks. Where sludge is taken direct from a settling tank, it is difficult to maintain proper concentration and homogeneity. The same is true of the sludge wells used to receive the sludge to be conditioned. In order to assure proper uniformity, these wells should be provided with means for effective agitation. Storage to tide over periods of idleness in the filter house is essential, but the tendency to provide so-called short time digestion tanks appears of doubtful value. If insurance against breakdowns and peak production only is required, it would seem that a five-day holding tank would give an adequate cushion.

Elutriation.—During digestion, soluble compounds are formed, which use up chemicals without benefit to filterability. To avoid this, a system has been devised whereby the sludge, prior to the addition of chemicals, is washed or elutriated, and the objectionable soluble compounds partially removed. Typical installations of this are at Wash-

ington, D. C., Baltimore, Md., Hartford, Conn., and Springfield, Mass. Here again, various factors besides the decreased use of chemicals must be properly weighed before the real economic value can be established.

Chemicals.—The matter of chemical dosage for conditioning has advanced considerably since the early use of sulfuric acid, and practice today is fairly well standardized to the use of ferric chloride and lime either singly or in combination. Lime is usually purchased unslaked in pebble size or as hydrated lime and is generally applied in the form of milk of lime. Ferric chloride is available in three forms: liquid, around 40 per cent, crystals about 60 per cent, and anhydrous about 98 per cent $FeCl_3$ and it is always added in solution.

In order to estimate the amounts of chemical necessary for proper conditioning, laboratory tests are often made by adding various doses to different samples, and filtering on a Buchner funnel. That such tests are indicative rather than absolute is probably due to the possibility that the sludge actually treated is not the same as that tested.

In calculating percentages of chemical used, the pounds of actual $FeCl_3$, dry basis, applied to each 100 pounds of dry sludge solids, should be recorded as the percentage of ferric chloride required for conditioning. The percentage of lime should be reported in the same manner, but care must be taken to state whether it is in the form of the lime as purchased, or reduced to a CaO basis. In order to avoid confusion and misinterpretation, published data should always report the quantity of lime used as CaO.

The old barrel and spigot have been replaced by automatic lime and ferric chloride feeders, which are now in general use, and notwithstanding some mechanical difficulties, the feeding of chemicals has now advanced to the point where definite control is possible. The feeders should be so specified that suitable ranges in quantities may be readily obtained to meet requirements due to changes in composition and concentration of the sludge to be conditioned. When feeding ferric chloride, it has been found helpful, for calculating purposes, to make the solution of such strength that one gallon contains one pound of $FeCl_3$. Such a solution has a specific gravity of about 1.095, and may be prepared from any of the forms of ferric chloride available.

The form in which the chemicals are to be purchased depends on size of plant, location, price and available facilities for storage and handling.

A review of the literature and observations made, show wide differences of opinion as to sequence and points of application of chemical. Some say lime should be added before the ferric chloride, others after. In the same plant, different conclusions have been reached by different operators. Good results have been obtained from both methods, but whether these results represented the most economical usage, is debatable. Ordinarily, the lime should be added first, and the ferric chloride near the outlet end of the mixing tank.

Mixing.—Addition of chemicals and mixing are closely related.

Air for mixing seems to be passing out of the picture. Horizontal rotation, with all manner of paddles to suit the individual fancy, have given way to vertical mixers in some installations. It appears to be generally accepted that the mixing period should be very short, and that the sludge be applied to the filters as quickly as possible. Appearance, rather than chemical tests, seems to be the index of proper conditioning.

Filtering.—In general, all makes of vacuum filters now available for sludge filtration, operate to produce a handleable cake, and a proper conditioning of the sludge is essential to that end. Major criteria of smooth filter operation following proper conditioning are: a cake, uniform in thickness and in moisture content; freedom from blinding or clogging and long life to the filter cloth; high yields; and a clear filtrate.

Results Obtained

Dewatering of sludge by conditioning and vacuum filtration is relatively so recent, that it is doubtful whether the published results actually represent all the facts and possibilities. In the laudable effort to be abreast of the times, editors seek articles on operation, almost before the wheels start turning. The obliging operator agrees. Usually, however, when his plant is thoroughly understood, and a definite routine has been established, it is found that materially different results are obtained than during the first few months. Thus, it may be that the original reports were too optimistic or perhaps too pessimistic. In view of the fact that lasting conclusions are often obtained from first impressions, great caution should be exercised in the release of data, unless there is assurance that time and mass effect of results have been sufficient to render true decision.

A survey of published data shows rather wide fluctuations in the amounts of applied chemicals, in moisture content of filter cake and in filter yields. This applies not only to different types of sludge, but also to sludge from the same plant. When it is remembered that most of these articles have appeared within the past five years, and that they as a rule represent first year's performance, the results must be accepted as showing a trend rather than absolute practice; on the other hand, one cannot help but be impressed with the indication that each sludge is a problem unto itself and must be treated accordingly.

In this connection, there is another point, approached with hesitation, but with the conviction that it is worthy of serious consideration. Most of our results are dependent upon laboratory control, and from this the overall performances are calculated. There can be no doubt as to the amounts of chemicals used over any given period, for these are a matter of invoice. But there is, unfortunately, some question as to the actual amount of sludge solids handled, particularly on the smaller plants. In the modern works, facilities are usually available for comprehensive analyses, which are often rendered useless by the inadequacy of sampling. It is possible to obtain reasonable accuracy, without undue burden upon time or effort, and simple calculations can

determine whether the solids are in balance. Accuracy in volume measurements and in sampling are essential to a true evaluation of all factors involved in sludge conditioning and dewatering.

Future Work

The practice of conditioning of sludge for dewatering by vacuum filtration, although growing rapidly, is by no means stabilized, and further progress awaits continued investigation and research on those installations now in service.

The selection of chemicals is fairly well standardized, but the proper amounts are still more or less a matter of trial and error. Whether or not to use ferric chloride alone or in combination with lime is still problematical, in some instances, at least. There is not only the cost factor to be considered (1.0 per cent ferric chloride is equivalent in cost to about 3.5 per cent CaO), but also for any given type of sludge, the effects of such factors as composition, concentration, uniformity, season, and temperature. Furthermore, the matter of proper laboratory control should be better understood, and to this end we believe that the art is sufficiently advanced to take stock in an attempt to evolve procedures which may become somewhat standard, or else acknowledge that each plant must stand on its own feet to meet its individual requirements. A committee representing chemists, engineers, manufacturers and operators, with subcommittees at work, could in the next few years collect and present data which would definitely show the facts and possibilities. Representative large plants are now in operation at Milwaukee, Wis., Chicago, Ill., Minneapolis-St. Paul, Minn., Washington, D. C., Baltimore, Md., Cleveland, Ohio, Buffalo, N. Y., Detroit, Mich., and other places, most of relatively recent construction. In New England, within a distance of sixty miles, there are four sizeable plants which have been recently placed in service, where within the next few years, much data should be available from elutriated digested primary sludge at Hartford, Conn. and at Springfield, Mass.; digested primary sludge at New Haven, Conn., Boulevard Plant; and undigested primary sludge at New Haven, Conn., East Street Plant. The results from all of the above and other places might well be studied and coordinated in a committee report by this Federation.

Summary

As matters now stand, we have more than a baker's dozen of different types of sludges produced in modern sewage treatment plants. Effective disposal of this sludge usually demands that it be dewatered, except in special cases, to a moisture content of 65 to 75 per cent. Sand beds are effective for this purpose, but have limited use. Conditioning with chemicals and dewatering on vacuum filters has become accepted practice and has shown rapid development within the past eight years, and particularly the last five.

Critical factors which must be considered in preparation for dewatering, are *Composition, Concentration* and *Chemical.* The *com-*

position is determined by the type of sewer system, type of treatment, season of the year, and whether or not the sludge is digested. *Concentration* depends also on the above considerations and in addition upon such other means as may be directed to this particular purpose. Coincident with *concentration* is the necessity for uniformity. *Chemical* is usually lime and ferric chloride, applied separately or ferric chloride alone. A short morning period is considered best.

While the general procedure has become standardized, there is still much to be learned relative to detail, and like all pioneer endeavor, the whole matter, except perhaps for those few places where experience is longest, is still more or less empirical. From data in hand, it is apparent that all types of sludges, unless complicated by exceptional circumstances, can be dewatered by this method. These data, however, show such wide fluctuations that any conclusions drawn must be made with reservations. That the process is sound, is without question. As to how it can be applied to greatest advantage and with best economy, is a matter which rests with time and future study of installations in service. To the end that a more complete understanding of the whole process of dewatering may be obtained, the Federation of Sewage Works Associations stands in an enviable position to render a real service to the public and to the art of sewage treatment, in general. It is fervently hoped, therefore, that attention may be focused on a proper gathering and evaluation of data which will enable this method of dewatering to be placed on such a basis that its adaptability, and economic possibilities may be fully established.

THE MANUFACTURE OF CHLORINATED COPPERAS AT THE BALTIMORE SEWAGE WORKS

By C. E. Keefer

Bureau of Sewers, Baltimore, Md.

It is timely to speak of the procedure used at Baltimore during the past two years to condition the sludge that is dewatered on vacuum filters. The experiments conducted in Baltimore [1, 2] from 1931 to 1934 on the filtering of digested primary sludge indicated that chlorinated copperas and ferric chloride were the best of several coagulants that were tried. Of these ferric chloride was better than chlorinated copperas. These observations were similar to those made on the dewatering of activated sludge in Chicago by Mohlman and Palmer.[3]

The experiments at Baltimore indicated that 1 lb. of ferric chloride was as effective as about 1½ lb. of chlorinated copperas. However, as copperas can be purchased in Baltimore at a very low price, the cost of making chlorinated copperas at the sewage plant was estimated to be much less than the cost of ferric chloride. Equipment was, therefore, provided in the same building with the vacuum filters and their accessories for making chlorinated copperas.

Copperas salt is discharged into a rubber-lined tank with a capacity of 3,600 gal. Water is added, and a propeller-type mixer operating at

420 rev. per min. is used to dissolve the copperas. A Duriron centrifugal pump with a capacity of 100 gal. a minute takes its suction from the bottom of the mixing tank and discharges the solution through a system of piping back into the top of the tank. During the first months of operation chlorine, which was drawn from 1-ton containers and measured by a Schutte and Koerting chlorinator, was injected into the suction side of the pump. It took from 24 to 30 hr. to make one batch of material containing about 5,000 lb. of chlorinated copperas. The chlorine is now introduced into the discharge piping from the pump with the result that the copperas can be chlorinated in about 10 hr. During the major portion of this period the chlorine is added at the rate of about 150 lb. an hour. Towards the end of the chlorinating period this rate must be decreased to prevent the escape of chlorine. After the copperas has been chlorinated, it is pumped into two rubber-lined storage tanks, each with a capacity of about 2,300 gal. From here the material is pumped as required into a coagulation tank, through which the sludge flows to the vacuum filters.

A saving has been effected at Baltimore by using chlorinated copperas. However, making this material is by no means free from difficulties. Vigilance must be exercised at all times to prevent the escape of chlorine. As copperas both before and after it is chlorinated is highly corrosive to ferrous metals, rubber-lined equipment and pipes or special metals must be used. At the Back River plant considerable quantities of Duriron and Durichlor pipes, valves, etc. are used. This material is quite brittle and must be handled with care. Duriron valves are liable to break if they are not carefully closed. When adjusting Duriron pumps, similar precautions are necessary.

During 1939 the cost of making chlorinated copperas amounted to $26.67 per ton on the anhydrous basis. It is expected that this cost will be considerably less than this amount during 1940. During 1939 the copperas cost $2.64 a ton. The following are pertinent data regarding the filtration of sludge and the cost of making chlorinated copperas during 1939:

Elutriated sludge:		
Solids, per cent		7.4
Volatile matter, per cent		55.2
Anhydrous chlorinated copperas used		
Lb. per 100 lb. of dry solids in sludge		3.88
Sludge cake production:		
Yearly output (wet), tons		24,351
Daily output (wet), tons		92.24
Moisture, per cent		73.7
Yearly output (dry solids), tons		6,341.28
Daily output (dry solids), tons		24.02
Dry solids per sq. ft. per hr.		5.43
Cost of making chlorinated copperas:		
Chlorine:		
101,476 lb. @ $0.02445	$2,481.08	
Hauling 50.738 tons @ $2.00	101.48	
		$2,582.56

Copperas:		
492.1 tons @ $2.641	$1,299.64	
Hauling 492.1 tons @ $0.86	423.19	
		$1,722.83
Operation:		
Labor	$333.00	
Electric current	44.00	
		$ 377.00
Maintenance		
Labor	$1,200.00	
Repair parts	669.80	
		$1,869.80
		$6,552.19

The experience at Baltimore during the past two years with filtering elutriated digested sludge from a population of about 800,000 persons indicates the following:

1. Chlorinated copperas is a satisfactory and economical coagulant for conditioning digested sludge.
2. After the coagulant is added to the sludge, filtration should proceed at once. Holding the material for 5 or 10 minutes will result in a lower filter yield.
3. Mixing the coagulant and the sludge by mechanical means is preferable to using compressed air. Mixing is not complete when air is used if the sludge is at all thick.
4. Sludge with a high solids content will give a greater cake production than sludge having a low solids content.

The Baltimore sewage-works is under the general supervision of George Cobb, chief engineer, Department of Public Works, and George E. Finck, sewerage engineer.

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Stream Pollution

AN INQUIRY INTO STANDARDS PROPOSED FOR STREAM CLEANLINESS *

By Abel Wolman

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The first national meeting of the Federation of Sewage Works Associations is a natural occasion upon which to discuss the basic criteria of virtually all of the activities of its membership. The determination of the extent of sewage treatment necessary to provide adequacy and safety of use of receiving bodies of water has always been a subject of engaging scientific character.

The answers to these fundamental questions of the profession and of the public have naturally taken on new importance as population densities have increased and as the uses of receiving bodies of water have multiplied. The natural scientific understanding of the issues involved has likewise advanced, although the empirical criteria used a half a century ago are today surprisingly unchanged as the result of more detailed technical knowledge.

The central question regarding standards proposed for stream cleanliness is revived today for two reasons. First, the entrance of the Federation of Sewage Works Associations into the national scene as a conscious forum for future discussion brings with it an added responsibility. Such a national body must now take stock of the bases of its activities. No more important one exists than this particular field which dominates the design, construction and operation of the facilities with which the Federation membership is concerned.

The second reason is that we are now entering an era of even stronger competition for the public dollar than has hitherto been the case. Public services in competition with vast defense enterprises must depend for their construction and operation dollar upon clear and convincing validities. Stock taking, therefore, in this instance implies rigid scrutiny of the purposes for which sewage treatment plants are to be constructed and operated. Criteria for these decisions cannot and must not be determined in a vacuum. They must rest upon the realities of the changing American scene and fiscal situation.

Standards for stream cleanliness have undergone extensive evolution within the last half a century. They have developed from the purely qualitative, aesthetic determinations of John Ruskin, the British poet and artist, to the detailed quantitative statements of M. M. Ellis of the Bureau of Fisheries. The poet bemoaned the disappearance of the sparkling, crystal clear brooks of England through the ravages of in-

* Presented at the First Annual Convention of the Sewage Works Federation, Chicago, Ill., Oct. 5, 1940.

dustrial and domestic wastes. His standard for cleanliness of streams was a simple one, a stream wholly undisturbed and completely free of everything but the natural wash of virgin soils of agricultural and forest use. Strangely enough the quantitative standards of Ellis essentially define such bodies of water as Ruskin longed for. The standards proposed by Ellis are descriptions of natural bodies of water quite undisturbed by any of the deleterious influences of modern civilization. The complex which he defines is the "ideal aquatic environment." Deviations from it, by the additions of other substances, are to be avoided.

Between these two chronological periods all gradations of approach to the problem are available, beginning with the estimates of Hering, Stearns, Hazen and Goodnough just preceding the Twentieth Century. The observations of this group, largely based upon the actual conditions created by sewage discharges, resulted in dilution values which are still remarkably helpful and simple for modern practice.

These observations of 50 years ago were followed by theoretical studies initiated and largely directed by Phelps. The studies at the Cincinnati station of the United States Public Health Service have further elaborated the technical bases of the newer standards.

In addition, the studies by Wolman in 1918, later confirmed and extended by Streeter, established the bacterial bases for many of the standards for raw water for water treatment plants.

All of these gave emphasis to the need for additional studies with particular reference to fish life, finally resulting in the extensive field and laboratory studies of the United States Bureau of Fisheries, and of many State fisheries groups.

The resultant increases in knowledge regarding the effects of discharges into receiving bodies of water have produced a literal flood of standards of cleanliness during the past 10 years. It is toward the control or the regulation of this flood that the present remarks are primarily directed. Are the standards now being promulgated with increasing velocity and perhaps decreasing validity adequate scientific and practical bases upon which the case for sewage treatment is to rest. Can the standards be met? Should they be met? Does the expenditure of the sewage treatment dollar rest upon a reasonable balancing of convenience and of public service?

This is not the place, of course, to review or to repeat the various standards proposed for water quality. It is sufficient to point out, however, that their number is great and that in many instances they are approaching the asymptote of the Ellis standards for the natural habitat of fish life. All gradations of standards, of course, are now available. Some define, as Ellis does, the characteristics of the receiving body of water, some define the quality of the discharges, while others range happily on both sides.

The trend, furthermore, is toward the adoption of standards on a wide geographical base by repeating the standards promulgated elsewhere, not always with the local conditions of use and necessity domi-

nant. This is not at all an unusual procedure in the making of standards. The fallacies as well as the validities of an existing standard tend to be perpetuated in succeeding ones.

In other areas of stream quality, particularly in the case of open bathing beach standards, the situation borders on the chaotic. This distressing state of affairs is being met by and large by classifications of areas, a frank concession, but a necessary one, to the balancing of practical necessities against epidemiological ignorance. In most standards, however, the philosophy predominates that, in the absence of knowledge, the more rigid the standard, the safer the engineer. How else can one account for the fact that one administrative agency suggests that the *Coli* density in open bathing beach waters should not exceed 5 per 100 c.c., while another, equally competent and diligent, stands firm for a maximum of several thousand per 100 c.c.? How long this state of tight-rope walking may continue with safety from attack by the public it is difficult to predict.

Unfortunately many of these definitions have crept into law and only now are they beginning to demonstrate their danger.

Proposals for Federation Activity

What should all of this mean with respect to the Federation? The writer proposes a series of activities by which the Federation may produce values important to the public and to its membership. These proposals are briefly discussed below:

1. *Testing the Results of Corrective Measures by Sewage Treatment*

For many years the advocates of sewage treatment have pointed out the values to be received by the adjustment of stream quality through the forces of sewage treatment. A limited number of followup reviews have been made of streams on which corrective measures have been established. Examples of such checks on reduction in pollution are the studies on the Raritan, the Niagara, the Scioto, the Illinois and the Potomac Rivers. The Federation should stimulate additional studies of this character in order to build up substantiating data for the promises made and for the development of practicable criteria for future enterprises. How far has promise been met by fulfillment and at what cost? The development of such reviews will gradually result in the establishment of a body of facts which should be rich in their availability for increasing diagnosis and treatment.

2. *The Economics of Standards and Correctives*

Almost all workers in the sewage treatment field are by this time familiar with the current unit—B.O.D. No discussion, no paper, no argument in this field proceeds far without the introduction and use of this unit of measure. May a plea be made for the introduction of a parallel unit of measure of equal importance, but hitherto unduly neglected in discussions of stream cleanliness? The unit proposed is

C.O.D., or cash on delivery. The engineer should be educated to exhibit an equal concern with respect to C.O.D. as he does with B.O.D. The Federation should enforce its obligations to bring back into focus the balancing of costs vs. benefits or C.O.D. vs. B.O.D.

In some instances, this balance of B.O.D. against the limitations of C.O.D. appears to be increasingly ignored. What is the warrant, for example, of a State Board of Health requiring a complete sewage treatment plant, including sand filtration, for a population on a highly polluted stream, where the effluent discharged has a quality infinitely superior to the probable quality of the receiving body of water below it for the next 25 years? Is it sufficient justification to say that the fixed and operating costs of such installations are sacrifices to the laudable desire to make a beginning in the cleaning up of the stream? How much should the first conscientious municipality be penalized for the delayed consciences of the remaining offenders?

Are per capita sewage treatment expenditures for capital investment as high as $50 to $100 warranted by the exigencies of such a case? Those members of the profession who are mathematically inclined should be persuaded to develop an "expediency index" which should be compared with the "sludge index" and other indices which now hold the stage in sewage treatment. An "expediency index" which is a function of per capita debt and of per capita B.O.D. reduction required for reasonable stream uses should appear in forthcoming sewage treatment plant tabulations.

May we further intrude with the suggestion that the Federation might begin to give consideration to what place in the list of priorities sewage treatment plants should take with respect to the increasing public services now exceeding a hundred functional types in the average large municipality. Where does and should sewage treatment appear in this list? Must it always have priority No. 1? Must the standards of stream cleanliness be at such a level as to require sewage treatment to supersede any other public service? Is the desire of some to raise the criteria of stream cleanliness to a level approaching that available in the time of De Soto, a sensible desire, even though it may be conceded that it is a praiseworthy one?

In the consideration of these questions should we not give serious thought to the anomalous situation which is created by the enforcement of some of the standards? Many of them, if put into effect, will produce a water environment of the vintage of 1500 A.D. with an adjacent land environment of the chronology of 1940 A.D. The waters bordering on certain municipalities or just below them will permit trout fishing by the people living on the adjacent land, who continue to be deprived of necessary services for the maintenance of health, welfare and safety. This imbalance of land and water environment seems to have been wholly lost sight of in the desire to raise to the highest point the levels of stream cleanliness. The results of encroachments of civilization make necessary the adjustments of not only the water but of the land environment.

Given a limited tax dollar, does governmental discretion demand that it must be spent to permit a maximum of fish life in a receiving body of water at the sacrifice of houses, hospitals, food, water supply, smoke prevention, etc. on land? If the cost of preserving the amenities in the land and in the water environment were so low that all could be accomplished with satisfaction, none of the issues need to be raised. In present operations, however, this condition of adequate funds for all purposes has not prevailed, does not exist and is not likely to appear in the near future.

Summary

The observations noted above, necessarily brief in character and deliberately antagonistic in form, are intended to indicate some of the basic problems with which the Federation might confront itself in the immediate future, through committee action or otherwise. These fundamental questions of sewage treatment and stream cleanliness may be summarized as follows:

(*a*) What are the quantitative bases for the standards so far promulgated in the United States.

(*b*) What are the controlling principles which should dominate the policy with respect to such standards.

(*c*) Are universal quantitative standards for stream cleanliness desirable.

(*d*) Are universal quantitative standards for effluents desirable.

(*e*) Is it possible to develop reasonable criteria of the economics of sewage treatment.

(*f*) What are the results of the installation of sewage treatment devices on stream cleanliness.

(*g*) What are the epidemiological aspects of sewage treatment programs.

These questions, of course, do not exhaust all of the aspects of the standards proposed for stream cleanliness. There are probably a dozen others. The objectives of this paper will, however, have been served if the standards now available and those being proposed from day to day are subjected to conscious objective scrutiny by a national body, not only in the light of the observations made above, but with respect to other realistic problems which now confront the engineer and the public administrator.

Virtually every city in the United States will be concerned in the next two decades either with increasing the degree of treatment for its sewage or with providing treatment facilities now wholly lacking. Expenditures for this purpose will probably exceed a billion dollars. No more important problem confronts the profession than how to steer a reasonable course between the perfectionists and the opportunists in this difficult field. "Sanitas sanitatum" is a good and militant slogan, but it should not transcend the cautions of common sense in the use and abuse of our streams.

Operators' Reports and Suggestions

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USEFUL NOMOGRAPHS IN SEWAGE TREATMENT

By W. D. Hatfield and George E. Phillips

Sometimes the nomograph is more useful in making certain calculations than the slide rule, while in other cases the slide rule is simpler; in still other cases graphs are more satisfactory than nomographs.

Figure 1 is a nomograph for calculating (1) pounds per day of suspended matter or B.O.D. in the sewage, or the pounds per day removed by different parts of the process and (2) population equivalent as calculated from the flow and the 5 day B.O.D. at 20° C. using 0.17 lb. per day per capita. This nomograph is easily constructed by setting three vertical lines A, B–C and D equidistant and parallel. The parts per million scale (A) and the flow scale in m.g.d. (D) are one-cycle log scales taken from a 10 in. slide rule scale. For convenience the D or flow scale is marked 1 to 10 but can be 0.1 to 1, 10 to 100 or 100 to 1000 m.g.d. The parts per million scale (A) is marked 100 to 1000 p.p.m. to fit raw sewages; however, for effluents one mentally points off 1 decimal place and the scale is 10 to 100 p.p.m. In this way both scales A and D are extended by mentally moving the decimal place rather than condensing the scales to three cycles to cover 1 to 1000 p.p.m. or m.g.d. By using the single-cycle log scales with a mental decimal place adjustment, much greater accuracy is obtained.

The center scales B and C are two-cycle log scales and are easily marked off from the two-cycle or "square" scale on the slide rule. Although the position of scales B and C may be calculated mathematically, most operators will find it easier to locate by trial calculations the 1,000, 10,000 and 100,000 points on the B and C scales and then draw in the other points from their slide rule scale. The equations for these calculations are those in Standard Methods of Water Analysis (A. P. H. A.), 8th Ed., p. 127; *i.e.*,

Pounds per 24 hr. = p.p.m. × m.g.d. × 8.34

Population Equivalent = p.p.m. 5-day B.O.D. × m.g.d. × 8.34/.17

Example in use of nomograph No. 1.

Flow—13 m.g.d., 5-day B.O.D.—220 p.p.m.

Set straight edge on 13 on scale D, keeping in mind that you have multiplied this scale by 10 in so doing, then on 220 on scale A, then

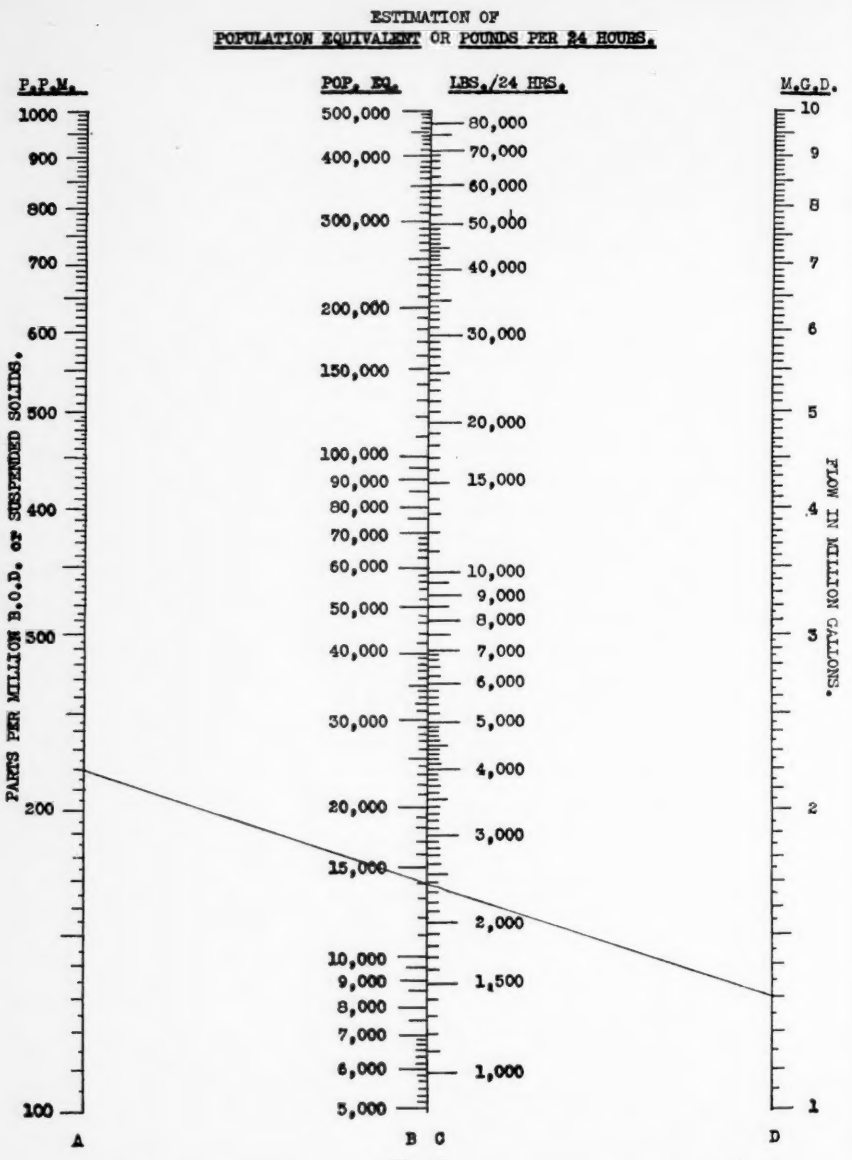

FIG. 1.

read population equivalent from scale B as 14,000 $\times$ 10, and lb./24 hr. from scale C as 2,380 $\times$ 10.

In case this example referred to an effluent of 22 p.p.m. the factors of scale D $\times$ 10 and scale A/10 would cancel and the answer would be read directly from scales B and C. The same method is used to calculate pounds removed by using the p.p.m. removed and the flow through process.

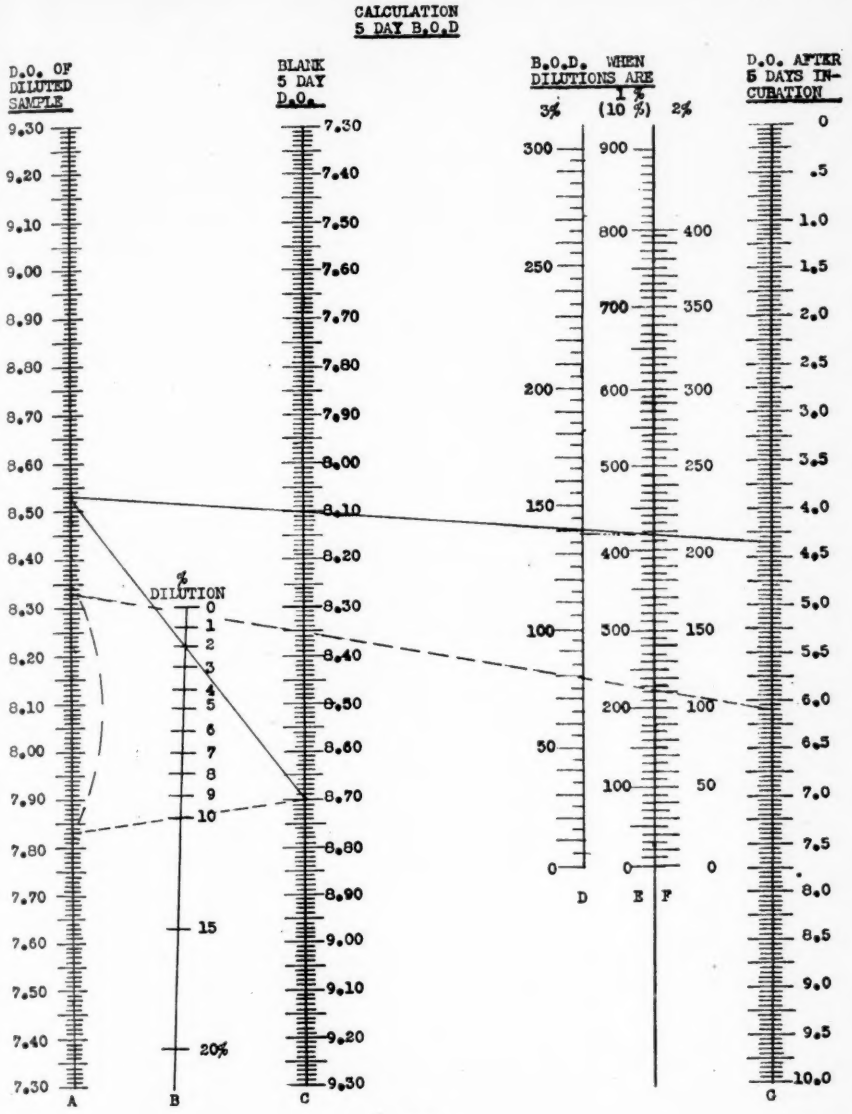

FIG. 2.

Another calculation made daily is that of the B.O.D. from the laboratory titrations for D.O. Figure 2 offers a rapid nomograph for this calculation. This nomograph is somewhat complicated to construct and reference should be made to books on the subject for the proper location of lines and scales. Examples in use of Fig. 2.

Raw Sewage

Data-Dilution 2 per cent; 5-day blank 8.7 p.p.m. D.O.
5 day incubated sample, 4.35 p.p.m. D.O.
To find 5-day B.O.D.

With straight edge start on scale C at 8.7 and pass through 2 per cent on scale B to point on scale A representing D.O. in diluted sample (8.53 p.p.m.) then swing edge to D.O. after 5 day incubation or 4.35 on scale D and read answer on scale F for 2 per cent as 208 p.p.m. Scale E can be used for 1 per cent or 10 per cent dilutions, the 10 per cent dilutions being of course 1/10th of the scale readings. If a 3 per cent dilution is used, the answer is read from scale D by swinging straight edge horizontally from E to D. Four and 5 per cent scales could be constructed using the 1 and 2 per cent scale as a swing line similar to the 3 per cent scale.

Example Final Effluent.

Dilution 10 per cent; 5 day blank 8.7 p.p.m. D.O.
D.O. sample 5.0 p.p.m. D.O.
5-day incubated sample 6.1 p.p.m. D.O.

Pass with straight edge from 8.7 on scale C through 10 per cent on scale B to D.O. of dilution water Scale A (7.83), to this add 10 per cent of sample D.O. or .50 (this is easily done by counting up .5 on scale A) to get 8.33; from here with straight edge to 6.1 on scale G and read effluent B.O.D. from scale E as 22 p.p.m.

If a 3 per cent or 30 per cent dilution is made the answer is read on scale D by a horizontal line from the scale EF. In our routine the 4 or 40 per cent and 5 or 50 per cent scales are not needed because we seldom make these dilutions. For those using 20 per cent dilutions of final effluents the A scale would have to be extended lower to be useful.

A SLIDE RULE FOR CALCULATING DEGREE OF OXYGEN SATURATION IN WATER SAMPLES

By A. A. Hirsch

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Solubility of oxygen in natural waters is dependent upon three factors: temperature, salinity and barometric pressure. The per cent saturation, frequently reported in analytical results, is based upon saturation values from Whipple and Whipple's oxygen solubility table in Standard Methods (1) which requires an awkward cross interpolation to obtain the saturation figure corresponding to a prevailing temperature and chloride concentration. In the majority of studies barometric pressure deviations from standard are neglected; when included the corrections are based on Henry's law.

The special slide rule illustrated enables a direct determination of per cent oxygen saturation from analytical results when the temperature °C., parts per million chloride, and barometric reading are known. On the top scale are rulings for parts per million oxygen as determined analytically; on the slide is a chart giving simultaneous temperature and chlorinity adjustments and also a barometric correction scale divided both in millimeters and in inches of mercury. The scale on the bottom stock is ruled to read per cent saturation.

This device is designed fundamentally to perform the division:

$$\frac{\text{p.p.m. dissolved oxygen found}}{\text{p.p.m. oxygen solubility under observed conditions}} \times 100 = \text{per cent saturation}$$

The dissolved oxygen and per cent saturation scales are divided logarithmically as in the usual slide rule but embrace only the range of figures met in practice. The denominator of this fraction is not expressed directly in terms of oxygen concentration but the slide is calibrated logarithmically according to the saturation values for the temperature, chlorinity and barometric combinations as marked. The barometric correction is simply a logarithmic scale to adjust the tabulated salinity-temperature relation according to the proportion:

$$\text{Solubility at observed pressure} = \text{Solubility @ 29.92 inches Hg} \times \frac{\text{Observed barometer}}{29.92 \text{ inches}}$$

The rule setting in the sketch shows the temperature-chlorinity relations for complete oxygen saturation at a normal barometer.

To use, set the point on the temperature-chloride concentration chart corresponding to environmental conditions opposite parts per million oxygen, as determined, on the top scale. The arrow S points to the per cent saturation on the bottom scale, if a standard barometer is assumed. To correct for barometric deviations, move the transparent runner (not shown) directly over the observed

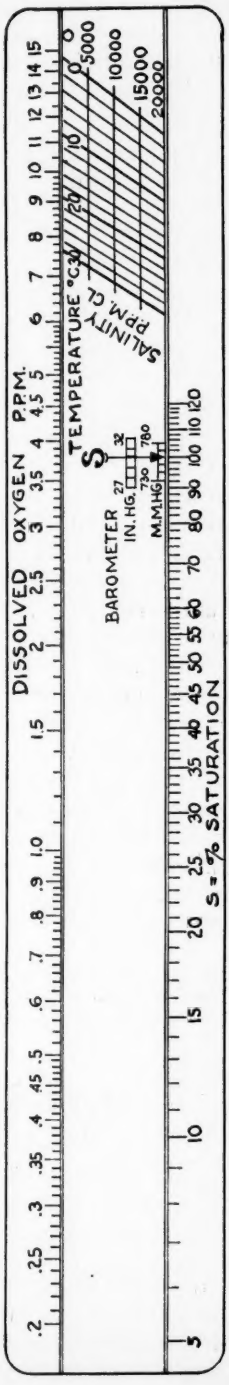

FIG. 1.—Per cent oxygen saturation slide rule.

pressure and read under the hairline on the bottom scale the completely adjusted per cent saturation figure. Application to a specific problem will clarify these directions.

Problem.—A water sample, taken from a stream at 22° C. while the barometer read 28.5 inches Hg, showed an oxygen concentration of 8.2 p.p.m. Titration showed 200 p.p.m. chloride. Find the per cent saturation using the special slide rule.

Solution.—Set the hairline (not shown) at 8.2 on the top scale. Locate on the temperature-salinity diagram a point corresponding to the field observations by following the 22° C. line down to an estimated ordinate of 200 p.p.m. chloride. Since the spacing is in 5000 p.p.m. chloride units, the desired point will be found at a distance of about 1/25 of the first horizontal division below the top of the slide. (For fresh water the chlorinity effect on solubility is, in general, negligible, the chloride correction being useful mainly for tide water and marine samples. Similarly barometric correction is important mainly for such special conditions as near surface samples taken during stormy weather or at high altitudes.) Set the required point within the temperature-chloride grid under the hairline. If the barometer were normal the arrow S would show the per cent saturation to be 93.5. To make the atmospheric pressure correction shift the hairline to the actual barometric figure and read 98.5 per cent saturation on the bottom scale directly under the hairline.

Aside from facilitating this special calculation, the rule also permits direct visualization and appreciation of the relative importance of temperature, chlorinity and atmospheric pressure effects on oxygen solubility in natural waters.

A rule for personal use may be most conveniently made by photostating the scales in the diagram to a dimension to fit and gluing the strips to a blank purchaseable, with an unbreakable runner, from the Lawrence Engineering Service, Peru, Indiana, at a nominal cost. Care must be taken to insure that the scales occupy the same relative positions as in the drawing.

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TWENTY-FIFTH ANNUAL REPORT OF THE DIVISION OF SEWAGE DISPOSAL, CITY OF SCHENECTADY, NEW YORK, 1939

BY MORRIS M. COHN, SUPT.

With the close of 1939, the sewage treatment facilities of the City of Schenectady end a full quarter-century of sanitation service, a record of continuity which is exceeded by few other major communities in the United States.

Past reports are replete with technical data on the problems of operation of a pioneering utility and the research and investigations which have made possible the solution of these problems. The end of twenty-five years of service finds the plant still in operatable condition and performing its sanitation functions with commendable efficiency.

With the close of a quarter of century of operation, and in keeping with the awakening of public interest in municipal sewage treatment and the control of pollution in our nation's valuable water courses, it is fitting to make this report a simple, popularized narrative rather than the technical review usually presented. It is difficult for the public to grasp the significance and the dangers of the vast amounts of unending wastes which are transported through our intricate network of sewers for decent and sanitary disposal. It is important, however, that the public realize the human and humane aspects of a problem which deals with the removal of wastes from man's habitat and the preservation of his surroundings in a safe and sanitary manner.

Early settlers in this valley built their homes on the banks of the picturesque Mohawk and around this nucleus grew the Dutch city of Schenectady. The river was good to the settlers and those who followed them. The stream served as a means of transportation that was more rapid and more comfortable than the early roads. From its depths the leisurely Dutchmen took fish to balance their diet. The cooling waters supplied many swimming holes and the ice loving Dutch gathered on the river for winter skating. Every Spring, the river brought rich alluvial deposits to enrich the low-lands from which the settlers took exceptional crops. The river supplied life-giving water to the community.

But as the community grew, and sewers were provided to remove the liquid wastes from homes and commercial establishments, the river became befouled and the water supply was driven from the river to a source that was free from man's own wastes. Year by year, more sewers were built and these sewers followed the path of least resistance into the Mohawk river.

A quarter century ago, motor transportation was not available to the good people of Schenectady and it was but natural for the Mohawk river to serve as the recreational center of the community. The Schenectady Boat Club thrived; all types of water craft were anchored along the Schenectady shore and weekends saw the river the scene of regattas and water recreation, just as Indian canoes must have skimmed over the surface of the Mohawk before white man's initiative made the valley a thriving vein of American progress.

It is significant that this love for the river resulted in a revolt against the discharge of crude sewage into the stream. Members of the Schenectady Boat Club interested the State Health Dept. in investigating fecal conditions in the stream and eventually forced Schenectady to construct proper treatment facilities to prevent the degradation of the river. Thus it was that in January, 1915, Schenectady opened one of the first modern sewage treatment plants in the

country. This plant has functioned with few modifications for a quarter of a century, performing well its task, even beyond its rated capacity to treat sewage.

Schenectadians use approximately 150 gallons of water per person per day and most of this water is returned to the sewer polluted with the wastes of life and living. The 14,000,000 gallons of sewage produced daily carry nearly 12 tons of foul solids in suspension and even greater amounts of dangerous organic wastes in solution. In addition, each drop of sewage contains thousands of bacteria, some of which are harmless and some potentially dangerous.

It is the function of the sewage treatment plant to treat approximately 9,000,000 gallons of sewage per day, the balance being unprovided for with sanitation facilities and thus being discharged in untreated form to the river. These 9,000,000 gallons of sewage contain solids which must be removed in large settling tanks; solids must be converted into a harmless humusy material by the proper cultivation and nurturing of "friendly" bacteria, much like a trained "bug circus"; the liquid from which the solids have been removed must be passed through acres of stone filters in which thrive other types of "friendly" bacteria which are capable of adding oxygen to the organic matter and destroying its power for evil; the harmless humusy solids must be dried to a cake on sand filter beds and removed and stored for sale to farmers and householders to be used as a fertilizer, thus returning to the soil the elements which came from it; millions of harmful bacteria must be removed from the sewage—all performed without nuisance in a plant which is well-managed, clean and orderly.

The sewage treatment plant of the type installed a quarter century ago depends on man's ability to utilize bacteria for his own well being, rather than permitting them to injure him. In order to make possible this "fortress of sanitation" it was necessary to deliver these vast quantities of polluted sewage to the treatment plant located on the river's edge at the City-Niskayuna line. For this purpose, a pumping station was erected in Riverside Park, within the confines of the old Dutch fort, and miles of large intercepting sewers were constructed and a huge concrete tunnel built for a mile and a half across country from the American Locomotive Company to the sewage treatment plant.

Much has transpired in the quarter century since lovers of the Mohawk river caused Schenectady to inaugurate a program of sewage treatment. In 1914, few plants were in existence in New York State and the total in the country numbered less than 1,000. Knowledge of the complex character and even more complex reactions of the staggering amounts of municipal wastes was woefully inadequate and Schenectady and other pioneering communities learned by cut-and-try methods.

But there has been an awakening of public conscience and a consequent demand for decent treatment of wastes of life and the social protection of our valuable streams. Today, state laws demand elimination of sewage discharges, public health laws require operation of

sewage treatment plants by licensed sanitarians, interstate compacts are protecting interstate waters, Congress has investigated national pollution control bills and a presidential message has called attention to the need for adequate sewage treatment.

Today, 5,500 sewage treatment plants are operating in this country and New York State boasts many hundreds. During 1939 alone, 850 sewage treatment plants have been installed at a cost of over $100,000,000 and serving over 11 million people.

Operation Results

Results of operation from the sewage treatment plant can be expressed in figures which are understandable to the sanitary engineer but, unfortunately, they fail to register in the lay mind. It is far more striking to state that 3,285,000,000 million gallons of polluted fluid has been treated during 1939; that the dangerous wastes in this staggering amount of liquid have been removed and transformed by the agency of bacterial action and that Schenectady has instead discharged billions of gallons of purified water into the Mohawk river.

Every day, approximately 9 million gallons of sewage have been treated, or enough sewage to fill Central Park Lake four times over daily. The amount of sewage treated during the course of the year was sufficient to cover the 10:38 sq. miles area of the City of Schenectady to a depth of over one and a half feet. Further striking evidence of the enormous volume of the municipal wastes is shown by the fact that these waters would require a freight train drawing 900 tank cars daily to handle the material which pours unceasingly through the city's sewer system to the sewage treatment plant.

From this sewage during 1939, the treatment plant removed 2,500 tons of fecal matter which, in the wet state in which sludge is handled, equaled 50,000 tons.

The extent of this material can best be visualized by stating that it would require a train carrying 1,200 freight cars to handle this tonnage.

In order to satisfy the organic matter, the oxidizing bacteria in the trickling filters have added over 82,000 lb. of oxygen to the sewage during 1939.

The handling of an unclean material like sewage and its residue entails serious responsibilities of plant maintenance both because of the dangers of insanitary conditions and the serious corrosive effect of the sewage liquor and sewage gases. The operation of the Schenectady plant has, therefore required a continuous program of structure maintenance equipment upkeep and ground landscaping and policing. The plant has presented a clean orderly appearance which has done much to win public favor for sewage treatment as a recognized sanitation utility.

Sewage Pumping

A portion of the sewage flowing through the sewer system was delivered to the treatment plant by gravity but the major portion was pumped by the sewage pumping station in Riverside Park. The public can easily visualize the huge pumps which constantly deliver the life-giving water of the community to our water fixtures but they know little of the continuous operating pumps which free them from their sewage wastes. These sewage pumps operate 24 hours per day with a portion of the unending load placed on the water pumps and during the course of a year they handle 2,190,000,000 gallons of liquid.

Operation of the sewage pumping station involves such tasks as protecting the pumps from the grit and debris contained in the sewage, maintaining the units in proper adjustment, keeping the station and grounds in meticulous condition.

Cost of Operation

A better knowledge of the problems of sewage treatment naturally leads to the question, "How much does this service cost?"

Despite the complexity of the problem and the age of the treatment and pumping utilities, Schenectady has obtained its sewage sanitation services at extremely low cost. The cost per capita for 1939 was 28 cents for the year, of which approximately 17 cents was for sewage treatment and 11 cents for sewage pumping. In terms of cost per volume of wastes handled, this service involved an expenditure of $8.52 per million gallons of sewage treated. This amounted to approximately one-half of one per cent of the city budget operations appropriation or less than $0.175 cents per thousand dollars property assessment.

Meteorological and Testing Service

In conjunction with the operation of the sewage treatment plant, weather plays an important role in the action of bacterial processes, drying of sludge fertilizer and the productiveness of the operating crew. It was, therefore, essential to establish a weather reporting station to serve as a means of explaining variations in operation efficiency and in anticipating the weather conditions that would affect operation procedures.

It has been found possible to make 20 years of weather records available to the general public and to such city departments as the law dept., welfare dept., and the Division of Streets and Sewers. The introduction of weather records in Court actions has been of value to the city in the prosecution of a number of its cases and this was equally true during the year of 1939.

For the past quarter of a century, the sewage treatment works has maintained a sanitary laboratory where full technical control has been maintained over the treatment process. In addition to routine

testing of the sewage as it enters the plant and as it leaves various stages of the treatment process, the laboratory has served as a chemical and biological research station from which has emanated information of value to the city and to other cities in the country.

During 1939, this laboratory carried out 2,000 determinations on sewages, effluents, sludges and city water. In addition, this laboratory, and its related materials testing laboratory, have served as the control station for various materials purchased by the city under specification requirements, and materials sold in the city under ordinance provisions.

Recommendations

In addition to the sewage treated by the plant, approximately 5,000,000 gallons of wastes per day are being discharged into the Mohawk river through various outlets, because of the inadequate capacity of the treatment plant.

It will soon become necessary to complete the treatment program inaugurated a quarter of a century ago and to thus eliminate all discharge of raw sewage. The description of the benefits of sewage treatment given above should serve as the strongest recommendation possible for the extension of this service to the point where all sewage is being properly treated.

Because of improved knowledge of the art of sewage treatment, and the efficiency which will result from the operation of a plant of mechanized nature, it will be advisable to provide for the total sewage flow of the city in a plant which would be a modernization of the present system. This mechanical means would avoid hand manipulations and result in greater efficiencies of operation.

The 12 tons of sewage solids collected daily would be pumped to heated digestion chambers where bacteria would work under the most favorable conditions to convert rapidly these solids into a harmless humus. The gas generated would be collected and amount to approximately 100,000 cu. ft. per day having a fuel value much greater than household gas used in Schenectady. This gas would be used for the production of power, light and heat.

The expansion of the sewage treatment processes would involve additional construction of intercepting sewers, the total project for treatment and interception probably costing in the neighborhood of $650,000 of which $400,000 would be for sewer work and $250,000 for the treatment plant.

It is strongly urged that this modernization and enlargement program be carried out.

AVERAGE ANALYSES, 1939

Constituent	Crude Sewage	Tank Effluent	Filter Effluent
Total Solids	541	414	375
Suspended Solids	177	57	36
Settling Solids	152	—	—
Biochemical Oxygen Demand	119	81	16
Free Ammonia	11.7	14.5	5.1
Albuminoid Ammonia Total	5.54	3.71	2.06
Nitrates	—	—	7.041
Nitrites	—	—	0.0453
Chlorides	34.8	32.7	30.2
Dissolved Oxygen	1.0	1.5	4.1
Per Cent Saturation	9.5	14.4	39.5
pH	7.3	7.3	7.3

EXISTING SEWAGE TREATMENT PLANT

Schenectady, N. Y.

Trunk Sewer

Length	8,300 feet
Cross-section	6 ft. wide by 3 ft. 7 in. deep in invert
Grade	1.63 ft. drop in 8,300 ft. length

Sewage Flow

Type of sewage	Fresh, domestic
Industrial waste	Practically none
Total sewage flow of city	14 m.g.d. estimated
Total flow treated	9.0 m.g.d. approx.
Population served by plant	65,000 persons, estimated

Bar Rack

Openings in clear	1½ inches
Screening capture	½ to ¾ yd. per day

Imhoff Tanks

Number of tanks	9
Depth-maximum working	13 ft. 10 in.
Detention period	2.5 hrs.
Sludge capacity	1.4 cu. ft. per capita
Scum and gas capacity	0.94 cu. ft. per capita
Number of gas vents	16 per tank
Area of gas vents	14.8 per cent of tank area
Area of gas vents	0.034 sq. ft. per cu. ft. sludge cap.

Dosing Tanks

Number	3
Type	Modified, semi-tapered
Size of siphons	30-inch Millers

Trickling Filters

Acres	3.07
Depth	5 ft.
Filter media	1 in. to 2 in. limestone

Sludge Beds

Area	0.87 acre
Area per capita	0.57 sq. ft. per capita

Emergency Pumping Station

Type of units	Centrifugal pumps, motor driven
Capacity	25 m.g.d.

Editorial

THE FIRST CONVENTION

The First Convention of the Federation was a success technically, socially and financially. It has established a precedent and a challenge for future conventions, but above all it demonstrated the value of friendly and mutually helpful cooperation between manufacturers and members. The exhibitors added a great deal to the technical value of the convention, and their financial aid was indispensable for the social program. Sometimes the entertainment at conventions is rough, crude and inadequate, but at the Sherman the smoker and banquet were enlivened by excellent, extensive and intelligent floor shows that seemed to please everyone. The pleasant social contacts at these affairs are important in building up a tradition and a desire to attend the next convention to renew old friendships and to establish new ones.

The exhibits were well arranged, interesting and informative. The manufacturers have been organized into an efficient body for many years, and with Herman Smith and O. T. Birkeness at the helm, they put on a show that must have won over all visitors to the desirability of cooperation between the Federation and the Manufacturers. Few First Conventions are able to start off with such a large and representative list of exhibitors. Thus the Federation will not have to wait years for development of this essential part of the annual convention, but it can share in the results of years of development by the American Water Works Association.

There were 55 exhibitors, and 173 representatives registered from a total of 80 companies interested in the sewage treatment field. These 173 registrants were very helpful in swelling the income, because they paid $7 to $10 for complete registration, as compared with $3 paid by non-commercial members of the Federation. Thus the latter benefited from the presence of so many manufacturers' representatives. Although the Manufacturers' Association had pledged $1,500 to meet the expenses of the convention, only $50 was used from this fund, and $1,450 will be turned over to the Federation to augment its 1941 income.

Registration of members of the Federation was most gratifying because of the widely scattering origin of the visitors. They came from 154 communities in 30 states. Illinois naturally led, with 114 registrants, from 42 cities; Indiana was next with 36 from 16 cities; New York next with 26 from 10 cities; Wisconsin next with 23 from 8 cities; and 26 other states were represented each by from one to 18 representatives. It was fortunate that so many state sanitary engineers were present. This was because the meeting dates were set just prior to the Conference of State Sanitary Engineers in Detroit on Oct. 7th.

The technical program was stimulating and comprehensive. Papers covered a wide range of interest, including sewage works operation, research, disposal of industrial wastes, disposal of garbage, and evaluation of standards for stream cleanliness. Dr. Wolman, possibly because of his close contact with the medical group at Hopkins, prescribed a counter-irritant to check any trend toward over-treatment of sewage beyond the requirements for stream sanitation. He urged that more attention be given to satisfaction of the C.O.D. than of the B.O.D.

One of the main features of this First Convention was the open discussion of the plans for reorganization of the Federation. An account of the proceedings is printed on page 1144 of this issue. On the evening of October fifth, a special meeting of the Board of Control was held. This was attended by 33 representatives and proxies. Every affiliate in the United States was represented. A very active discussion of the proposed new Constitution and By-laws was carried on, and agreement was reached on practically all proposed measures. A few details were left to the discretion of a Sub-Committee, which has since reported to Chairman Emerson, thus paving the way for final action at the January, 1941, meeting of the Board of Control. Minutes of the Special Meeting are printed on page 1146 of this issue.

One feature of the Convention, the Operators' Breakfast on Saturday morning, was followed by a discussion of perennial topics such as disposal of sludge, balance of suspended solids vs. sludge measurement and analysis, and similar subjects. This session was curtailed because of a full program Saturday. If similar sessions are included in future conventions, ample time should be allotted, and the discussions should be limited if a tendency towards reminiscence develops. If well executed, this type of program can be of practical value to plant managers and operators.

The First Convention demonstrated that the Federation needs an annual meeting; that this meeting will not interfere with or supplant local or group meetings; and that cooperation between technical, academic and commercial men is necessary for a well-rounded, successful convention.

F. W. MOHLMAN

Proceedings of Local Associations

PENNSYLVANIA SEWAGE WORKS ASSOCIATION

Fourteenth Annual Conference

State College, Pennsylvania, June 26–28, 1940

The fourteenth annual conference of the Association was held, as usual, on the beautiful campus of Pennsylvania State College, June 26 to 28, inclusive. Following a welcome upon the behalf of the College by Professor Raymond O'Donnell, well beloved past president of the Association, the conferees heard genuinely worthwhile papers upon the latest advances in the science as well as the art and practice of sewage treatment presented by Messrs. E. W. Gilliland, Frank Woodbury Jones, Eugene B. Swinehart, H. W. Gehm, John T. Campbell, T. R. Haseltine, W. W. Hodge, J. R. Hoffert, Gordon J. Weist, M. M. Stiles, Lewis L. Gwin and C. F. Grace. The clinic, under H. M. Freeburn, devoted to operator's problems as usual brought a hearty response from the men who do the actual denaturing of sewage, and the discussions throughout the sessions were actively participated in by the conferees and developed many helpful and practical ideas.

In keeping with the Association's continued growth, this conference was bigger and better than ever with over 177 conferees registered, including some of the most distinguished men in the profession. Nearly all of those present crowded the dining hall of the Nittany Lion Inn for the annual banquet which was presided over by our perennially delightful toastmaster "Ted" Moses. It was "keynoted" with a fine address by Robert Spurr Weston, and highlighted by the presentation of gold keys to all the past presidents of the Association including President Emeritus Professor Elton D. Walker. A key was also presented to "Deacon" Matter who, after giving ten years of smilingly efficient service to the upbuilding of the Association as its Secretary-Treasurer, insisted upon retiring.

At the business session the Association adopted the report of the Committee submitting a proposed law for the licensing of sewage works operators; adopted the customary resolutions; and elected the following officers for the coming year: *President,* George P. Searight; *First Vice-President,* E. B. Swinehart; *Second Vice-President,* T. S. Bogardus; *Secretary-Treasurer,* Bernard S. Bush; *Editor,* J. R. Hoffert; representatives to Sewage Works Federation, H. E. Moses and Charles A. Emerson, Jr. Unofficially, Frank Woodbury Jones was elected Chaplain as a result of his profound and witty sermon upon sewage plant maintenance.

As usual, the Association pundits leavened their mental efforts with their annual contests with the Pennsylvania Water Works Association

in golf and soft ball, or included side trips to the Fisherman's Paradise along Spring Creek, visited the Rockview Branch of the Western State Penitentiary, the chemical limestone mines, etc., according to their preferences. "Casey" Jones and his committee provided the honest-to-goodness prizes for the winners and Mrs. Myron Mansfield supervised the entertainment for the ladies.

With the closing of the conference, the conferees put June 23–27, 1941, on their "must" list.

J. R. HOFFERT, *Editor*,
Pennsylvania Sewage Works Association

NORTH DAKOTA WATER AND SEWAGE WORKS CONFERENCE

Twelfth Annual Meeting

Wahpeton, North Dakota, September 26–28, 1940

The meeting was opened on Thursday, September 26, at 10 A.M. by President William J. Nordley. President Nordley in an address to the Conference reviewed the activities of the past year. He pointed out that the committees on phosphates, jointing compounds, and licensing and certification continued to function throughout the year. New committees appointed during the year were: Committee on Meter Repairs, Committee on Membership, Committee on Publicity, and Committee on Convention Program. Mr. Nordley thanked the chairman and committee members for their efforts and accomplishments.

The president officially represented the Conference at the Montana Section meeting of the A. W. W. A. in April. He cited his observations at this meeting. The president reported that the treasury as of September 26, showed a net balance of about $130 as compared to a net deficit a year ago of $16. He cited that during the Conference year there was a total of 119 paid memberships as compared with 86 during the previous year. The Official Bulletin was enabled to carry photographs on the front cover and all costs of printing, publishing, and mailing of this publication were borne by the Conference. Typists and printing facilities were contributed by the State Department of Health.

In closing, the president pointed out that the Conference should work toward the certification of operators with the end in view of eventually bringing a state licensing law to the State Legislature. He also pointed out that enough memberships in the American Water Works Association should be obtained in order that a Dakota Section may be formed.

The Secretary read the minutes of the last meeting and they were approved as read.

The secretary presented the financial statement as of September 25, 1940. Approval of this statement was withheld pending the examination of same by the Auditing Committee.

Under new business, there was a discussion of the possibility of sending the Conference president to one out-of-state meeting in a year providing the funds are available in the treasury. It was moved by L. W. Veigel and seconded by Ed. Tschida that the secretary-treasurer be authorized to allow up to $25, if the money were available, as expense money for the president of the Conference to attend one out-of-state meeting as official representative of the Conference. This motion was amended by J. Kleven and seconded by S. K. Svenkeson that the figure of $25 be deleted from the motion and that if the president were to attend such out-of-state meeting as an official representative all of his expenses should be paid with no limitation. The attendance of the president at such a meeting should be with his approval and/or at his discretion. Motion carried.

There was a discussion of the most suitable dates on which our annual convention should be held. There seemed to be a divided opinion as some of the members favored a spring meeting and others favored a fall meeting. It appeared that the middle of the month is more satisfactory than the first or the last of the month. A large number of the members thought October would be a satisfactory time. It was moved by S. K. Svenkeson and seconded by J. Kleven that a committee of six be appointed to recommend satisfactory dates for the next convention. Motion carried.

It was moved by Tschida and seconded by C. S. Childs that a certificate of membership be given to all those members of the Conference who did not now have one and to all new members and that a membership card be given annually upon the payment of membership dues. Motion carried.

An informal discussion was held on methods of getting out more publicity and more information regarding the Conference and its purposes.

The Committee on Licensing and Certification was instructed by President Nordley to contact as many of the delegates as possible and to make a report at the business meeting on Saturday morning, September 28.

The following committees were appointed by the president, Mr. Nordley, to function for the duration of the convention:

Auditing Committee: L. W. Veigel, Dickinson, chairman; Carl Isaakson, San Haven; R. J. Lochner, Cooperstown.

Convention City Committee: Ora C. Ayliffe, Fargo, chairman; E. Tschida, Dickinson; J. S. Sorenson, Grenora; E. J. Pearson, Minot.

Resolutions Committee: Steve Monek, Jamestown, chairman; M. L. Lovell, Beach; Lee Ottaway, Devils Lake; P. L. Eide, Fargo.

Nominations Committee: Sig Ravnos, Mandan, chairman; S. K. Svenkeson, Minot; H. Hintgen, Wahpeton.

Meeting was adjourned at 12:30 P.M.

Meeting was called to order at 10:30 A.M. on Saturday, September 28, 1940. President Nordley called for the reports of the various committees which were as follows:

Auditing Committee: L. W. Veigel reported that the financial statement of the secretary-treasurer was true and accurate and that the Conference approve of same. It was moved by R. M. Jenson and seconded by Sig Ravnos that the Auditing Committee report be accepted. Motion carried.

Resolutions Committee: Report of this committee was presented by Steven Monek, chairman, which was as follows:

WHEREAS, the North Dakota Water and Sewage Works Conference has held its 1940 annual meeting in the City of Wahpeton, North Dakota, and

WHEREAS, the City of Wahpeton has welcomed the members of the Conference and given them the most hospitable and friendly reception,

NOW THEREFORE, be it resolved that the Conference extend a vote of thanks to the city officials, the Chamber of Commerce of Wahpeton, the members of the local committee, and to the people of Wahpeton, North Dakota.

WHEREAS, we have learned of the death of Chris Duchscher of Jamestown, North Dakota, who has been a member of our Conference for many years, and,

WHEREAS, Chris Duchscher has long served the public as water plant operator at Jamestown,

NOW THEREFORE, be it resolved that the Conference extend its sympathy to Mrs. Chris Duchscher and family.

WHEREAS, the North Dakota State Department of Health has cooperated with the North Dakota Water and Sewage Works Conference through its Division of Sanitation, and

WHEREAS, the personnel of the Health Department have at all times cooperated with the Conference in its activities, and

WHEREAS, the facilities of the Health Department have been utilized in the publishing of the Official Bulletin, and

WHEREAS, the Conference desires the continuance of this cooperation,

NOW THEREFORE, be it resolved that the Conference extend a vote of thanks to the North Dakota State Department of Health.

WHEREAS, the waters of streams in the State of North Dakota have in many instances become polluted by the dicharge therein of untreated wastes from public, industrial, and private sources, and

WHEREAS, such pollution is detrimental to the domestic water supply of communities situated along such streams, and, further, such pollution is inimical to wild life and recreational facilities, and

WHEREAS, there is a bill pending before the Congress of the United States, known as the Barkley Bill, which bill, if passed, will serve the purpose of eliminating, or greatly reducing such pollution,

NOW THEREFORE, let it be resolved, that the North Dakota Water and Sewage Works Conference go on record as approving the passage of said Barkley Bill, and requesting the secretary of this organization to forward copies of this resolution to the North Dakota members of the Congress of the United States.

WHEREAS, President E. F. Riley and Professor Cavanaugh of the Wahpeton State School of Science have greatly assisted the North Dakota Water and Sewage Works Conference by their cooperation in providing laboratory facilities for the use of this Conference,

NOW THEREFORE, be it resolved that the Conference extend a vote of thanks to President Riley and Professor Cavanaugh.

WHEREAS, during the past several years the Conference has been working towards the establishment of a system of licensing for municipal water and sewage plant operators, and

WHEREAS, it is the sense of this Conference that the establishment of a licensing system for said operators is desirable,

NOW THEREFORE, be it resolved that this Conference act on the recommendation of its Committee on the Licensing of Operators and institute a system of such licensing.

It was moved by Dean Chandler and seconded by L. H. Kirke that the resolutions as read be adopted and copies of same given to the press. Motion carried.

Convention City Committee: Reported by Ora Ayliffe, chairman, that Jamestown was selected as the convention city for 1941.

Nominations Committee: Reported by chairman Sig Ravnos the following nominations: R. M. Jenson, Grand Forks, *President;* E. J. Pearson, Minot, *Vice-President;* L. K. Clark, Bismarck, *Secretary-Treasurer;* Wm. J. Nordley, Edgeley, *Director;* and D. B. Norris, Minneapolis, *Director.* Moved by Dean Chandler and seconded by Kleven that the officers recommended by the committee be elected by a unanimous vote. Motion carried. Response was given by Mr. Jenson and Mr. Pearson.

LLOYD K. CLARK, *Secretary*

Federation Affairs

FIRST ANNUAL CONVENTION SEWAGE WORKS FEDERATION

Chicago, Ill., Oct. 3–5, 1940

The First Annual Convention of the Sewage Works Federation was held at the Sherman Hotel, in Chicago, Oct. 3 to 5, 1940. For several years the need for an annual convention has been discussed at the annual meetings of the Board of Control in New York in January, but it was not until the meeting of January, 1940, that an invitation was extended for the first convention. This invitation came from the Central States Sewage Works Association. The invitation was accepted in March, 1940, and the officers of the Central States Association started immediately to prepare for the convention.

A Convention Committee of the Federation was appointed by Chairman Emerson, consisting of Messrs. M. M. Cohn, F. W. Gilcreas, F. W. Mohlman, W. J. Orchard, B. A. Poole and G. J. Schroepfer, *Chairman.* This Committee exercised general supervision over the pre-convention arrangements and cooperated with the Local Committee and the Central States Association officers.

The Central States Association arranged to combine its 1940 meeting with the Federation Convention. This precedent will probably be followed in future conventions of the Federation, when held in other parts of the country.

The Convention Committees were as follows:

Attendance and Publicity

Anthony Anable, *Chairman*

A. J. Wagner
A. S. Bedell
E. J. Cleary
M. Cohn
L. H. Enslow
Geo. B. Gascoigne (Deceased)
S. A. Greeley
L. R. Howson
C. G. Hyde
K. L. Mick
F. W. Mohlman
Wm. M. Piatt
L. Van Kleeck

Program

C. K. Calvert, *Chairman*

L. H. Enslow
C. V. Erickson
C. G. Hyde
K. L. Mick
Langdon Pearse
Willem Rudolfs
C. N. Sawyer

Local Arrangements

F. W. Mohlman, *Chairman*
O. T. Birkeness
W. W. DeBerard
Paul Hansen
R. S. Rankin
H. E. Schlenz

Finance

W. J. Orchard, *Chairman*
W. W. DeBerard
Paul Hansen
F. W. Mohlman

Mfgrs. and Exhibits

O. T. Birkeness, *Chairman*
Frank Lovett
R. S. Rankin
Milton Spiegel
J. Herman Smith

Entertainment

H. E. Schlenz, *Chairman*
C. B. Cox
R. C. Hageman
Clinton Inglee
J. R. Palmer
R. W. Peterson
P. O. Richter

Ladies Entertainment

Mrs. Paul Hansen, *Chairman*
Mrs. L. I. Birdsall
Mrs. W. W. DeBerard
Mrs. Wm. A. Dundas
Mrs. L. M. Johnson
Mrs. F. W. Mohlman
Mrs. J. R. Palmer
Mrs. Langdon Pearse
Miss Gladys Swope

Hotel and Registration

E. Hurwitz, *Chairman*
Rolf Eliassen
Carl Schwob
J. I. Smith

Transportation

L. M. Johnson, *Chairman*
A. H. Goodman
L. M. Mercer
U. F. Turpin

The committees started to work in April. The Sherman Hotel was chosen for the meeting, because of its excellent facilities for exhibits and its able Convention Department. The choice of hotels was a wise one, and the thanks of the Federation are due Messrs. Frank Bering, Earl Benedict and Joseph Brunette, for their unfailing courtesy and helpfulness in planning the affairs of the Convention.

The Technical Program was as follows:

Thursday, Oct. 5

1. "New Developments in Activated Sludge Plant Operation." By Gail P. Edwards. Discussion by Don E. Bloodgood.
2. "The Role of Sphaerotilus Natans in Activated Sludge Bulking." By C. C. Ruchhoft and John F. Kachmar, Jr. Discussion by H. Heukelekian.
3. "The Role of the Trickling Filter in Sewage Treatment." By Max Levine. Discussion by Linn H. Enslow.

4. "New Operating Results in the Chemical Treatment of Sewage." By Willem Rudolfs. Discussion by E. Hurwitz.
5. "Sewage Flows and Composition Affecting Treatment." By A. M. Rawn. (Read by H. W. Jewell.) Discussion by Robert A. Allton.
6. "Recent Trade Waste Disposal Methods." By E. F. Eldridge. Discussion by L. F. Warrick.

Friday, Oct. 6

7. "Progress in Conditioning Sludge for Dewatering." By Frank W. Jones. Discussion by Harry A. Faber and C. E. Keefer.
8. "Mechanical Equipment in Sewage Treatment." By Lloyd M. Johnson. (Read by A. H. Goodman.) Discussion by C. G. Hyde. (Read by T. R. Kendall.)
9. "Sludge Gas Utilization." By Ralph E. Fuhrman. Discussion by W. B. Walraven.
10. "Dural Disposal—Where Does It Stand?" By Edward J. Cleary. Discussion by L. R. Howson.
11. "Instruction in Sewage Treatment." By Gordon M. Fair. Discussion by H. E. Babbitt.
12. "Licensing Sewage Plant Operators." By Charles C. Agar. Discussion by C. W. Klassen.

Saturday, Oct. 7

13. Operators' Breakfast. K. L. Mick and M. W. Tatlock, Discussion Leaders.
14. "An Inquiry Into Standards Proposed for Stream Cleanliness." By Abel Wolman.

Papers 1, 2, 3, 4, 7, 9, 10, 11, and 14 are published in this issue. The remaining papers will be published in the next issue (January, 1941).

An inspection trip was made to the Southwest Treatment Works of The Sanitary District of Chicago on Saturday afternoon.

Entertainment included a smoker Thursday evening, with a large number of first-class night club acts. The Banquet on Friday evening had an attendance of 600. A remarkably fine and intelligent floor show, followed by dancing, provided excellent entertainment. During the evening, Mr. W. W. DeBerard on behalf of the Central States Sewage Works Association presented gold watch charms, in the shape of an Imhoff cone, to Past Presidents Finch, Mohlman, Warrick, Babbitt, Calvert, Poole, Schroepfer, Nichols, Leonard, Dawson, Kramer (deceased) and Ferguson (deceased).

The Ladies' Entertainment Committee, under the chairmanship of Mrs. Hansen, provided delightful entertainment for the visiting ladies. Thursday afternoon a bus trip followed Sheridan Road to Lake Forest, where the gardens and buildings of the Lasker Estate were visited.

Later, tea was served at the home of Mrs. Henry Pope. Friday's entertainment included a tea and style show at Marshall Field and Company. Various shopping and sightseeing trips filled all spare time.

The paid registration at the convention was 556 and attendance ran well over 600. There were representatives present from 154 communities in 30 states.

The exhibitors' registration totalled 173. Eleven registered from one company, nine from another. There were 55 exhibitors, all of whom had most attractive exhibits. The Manufacturers' Association, under the able management of Jay Herman Smith handled the rental and assignment of booth space. The exhibitors were as follows:

Aluminum Co. of America
American Brass Co.
American Cast Iron Pipe Co.
American City Magazine
Ayer McCarel Reagen Clay Co.
Builders Iron Foundry
Carson-Cadillac Corp.
Carter Ralph B. Co.
Chain Belt Co.
Chapman Valve Mfg. Co.
Chicago Pump Co.
Crane Co.
Dorr Co.
Dow Chemical Co.
Engineering News Record
Everson Mfg. Co.
Fairbanks Morse Co.
Farnham, F. D., & Co.
Foxboro Co.
General Chemical Co.
General Electric
Homelite Corp.
Inertol Company, Inc.
International Filter Co.
Jeffery Mfg. Co.
Johns-Manville
Lakeside Engineering Co.
Linings, Inc.
Link-Belt Co.
Lock Joint Pipe Co.
Mathieson Alkali Works, Inc.
Merco Nordstrom Valve Co.
Monsanto Chemical Co.
Mueller Co.
Nichols Eng. & Research Corp.
Pacific Flush-Tank Co.
Pennsylvania Salt Mfg. Co.
Pittsburgh Equitable Meter Co.
Portland Cement Association
Proportioneers, Inc.
Public Works Magazine
Rascher & Betzold
Royer Foundry & Machine Co.
Sewage Works Engineering
Simplex Valve & Meter Co.
Smith A. P. Co.
Tapax Manufacturing Co.
Tennessee Corp.
U. S. Pipe & Foundry Co.
Vogt Mfg. Co.
Wailes Dove-Hermiston Corp.
Wallace & Tiernan Co., Inc.
Water Works & Sewerage
Wood R. D. Co.
Yeomans Bros. Co.

The Manufacturers' Association turned over $1,500 to the Local Committee, which was added to the income from registration to meet the expenses of the convention. After all bills were paid, the balance was $1450.08. This will be turned over to the Federation by Financial Chairman Orchard, who deserves the thanks of all those connected with the convention for his successful handling of the finances.

F. W. Mohlman,
Chairman, Local Committee

MINUTES OF THE BUSINESS MEETING OF THE FEDERATION OF SEWAGE WORKS ASSOCIATIONS

Chicago, Illinois, October 5, 1940

A feature of the First Annual Convention of the Federation of Sewage Works Associations was the Business Meeting of the Federation held Saturday, October 5, 1940, at the Hotel Sherman, Chicago. Chairman C. A. Emerson presided and called the meeting to order at 10:15 A.M. The large attendance evidenced the interest members felt in matters to be discussed, particularly that of proposed changes in the Federation.

The Report of the General Convention Committee was presented by George J. Schroepfer, Chairman. The report refers to its appointment on January 20, 1940, to determine (1) whether a convention should be held during the year 1940, and (2) if it was the desire of the membership to have such a convention, to make the necessary arrangements therefore. It then states—

> The first question as to whether a convention should be held was readily disposed of in view of the overwhelming sentiment in favor of such a convention this year, as expressed by the officers of the member associations. The answer to the second problem is to be found in the attendance, and in the arrangements which have been made by the various committees in an effort to make this meeting an entertaining, interesting and profitable one to the membership.

The committee acknowledges and commends the fine work and cooperation accorded by the various working committees. As having a bearing on the general question of an annual convention, the committee states—

> In arranging for this convention, the members of the general committee were in contact with a relatively large percentage of the membership of the Federation. The spontaneity of their co-operation and the warmness of their expressions in favor of a convention and increased activity on the part of the Federation were very encouraging and enlightening. The fact that this convention was a "natural" augurs well for the future of the Federation since the need and the desire for increased activity and a stronger Federation definitely exist. As a result of its contact and the expressions of opinion it has received, the committee expresses itself as heartily in favor of the reorganization and revitalization of the Federation along the general lines recommended by the committee which has worked on this question for more than a year.

It was moved that the report be accepted and that the Board of Control be requested to arrange for a national convention each year; motion seconded and carried.

The meeting next considered the Report of Committee for Expansion and Reorganization. Chairman Emerson stated that the Committee had been created by authorization of the Board of Control at its Annual Meeting on January 18, 1940. He gave the personnel of the Committee and told of the large amount of work performed both by several meetings of small groups and by correspondence throughout the country in order to have opinions from a large group having

varied interests and viewpoints. From all these efforts there has been produced the report of the Committee dated September 18, 1940. This report has been distributed to all Board of Control members, and to Secretaries of all affiliates for transmission to their officers and executive boards. Also, a number of copies were sent to persons active in Federation matters and interested in its welfare.

Mr. Emerson briefly reviewed the principal features of the proposed Amendments to the existing Constitution and By-Laws and explained their purpose and the need for such changes. The Chairman then called on several members to discuss the matter. B. A. Poole related that the Central States Sewage Works Association on October 4, 1940, by unanimous vote adopted the following resolution:

WHEREAS the Federation of Sewage Works Associations has never been entirely self-supporting and

WHEREAS balance sheets for the past few years show apparent slight profits, they do not take cognizance of contributions in money and the donation of salaried time of clerical help as made by individuals or organizations and which cannot be expected to be continued indefinitely and

WHEREAS it is necessary that additional funds must be made available if our present position is to be maintained, our activities are to be expanded, and our usefulness to our membership is to be increased and

WHEREAS the constitutional objectives of the Central States Sewage Works Association would be more effectively accomplished by the strengthening and reorganization of our Federation.

Now therefore be it resolved that the members present at the 13th Annual Meeting endorse the general principle of reorganization and strengthening and direct their officers to proceed with the necessary steps toward the organization of a stronger, more effective, and more useful National Federation of Sewage Works Associations.

Chairman Emerson reported that on September 16 the governing board of the California Sewage Works Association had gone on record endorsing the principles of the proposed changes, this on authority of a letter from Secretary Ingram. This was confirmed by Clyde C. Kennedy, San Francisco, California, who spoke in support of the proposed movement. Dana E. Kepner, Denver, Colorado, told of similar agreement with the idea by the Rocky Mountain Sewage Works Association at a business meeting on February 8, 1940, the matter being left in the hands of their executive board. N. L. Nussbaumer, Buffalo, New York, stated that the Executive Committee of the New York State Sewage Works Association at a meeting this fall was substantially in accord with the proposed changes.

Others who spoke by request of the Chairman were Langdon Pearse, Chicago, Illinois; Morris M. Cohn, Schenectady, New York; and William J. Orchard, Newark, New Jersey.

General discussion followed, concluding with the adoption of the following resolution, on motion, seconded and carried:

WHEREAS the Committee on Expansion and Reorganization has studied the needs of the Federation of Sewage Works Associations and has prepared a revised Constitution and By-Laws which will establish procedures to meet the present needs of the Federation of Sewage Works Associations

WHEREAS the First National Sewage Works Convention held in Chicago on October 3–5 in conjunction with the Central States Sewage Works Association had the approval of the State Associations

WHEREAS the technical and professional success of the Convention has demonstrated the important service which a strong and expanded Federation can render

Therefore be it resolved that this meeting approve the spirit and intention of the strengthened and expanded Federation and recommends to the Board of Control that it take favorable action on the proposed revisions and additions to the Constitution and By-Laws.

The meeting adjourned at 11:40 A.M.

H. E. MOSES,
Secretary-Treasurer

MINUTES OF THE SPECIAL MEETING OF THE BOARD OF CONTROL. FEDERATION OF SEWAGE WORKS ASSOCIATIONS

Chicago, Illinois, October 5, 1940

A Special Meeting of the Board of Control, Federation of Sewage Works Associations, was held at the Hotel Sherman, Chicago, Illinois, on October 5, 1940, called by C. A. Emerson, Chairman, by written notice sent to all Board Members on August 1, 1940. Following dinner Chairman Emerson, presiding, convened the meeting at 7:35 P.M. Thirty-three representatives were present, twenty-two of whom were Board Members, the remainder attending by virtue of proxies. Every affiliate in the United States was represented; the Canadian Association by proxy. The only groups unrepresented were the two in England and the one in Argentina. The details of representation are as follows:

Present in person:

Name of Affiliate	*Name of Representative*
Central States Sewage Works Association	W. W. DeBerard
Central States Sewage Works Association	George J. Schroepfer
Dakota Water and Sewage Works Conf.	W. W. Towne
Federal Sewage Research Association	A. P. Miller
Georgia Water and Sewage Association	Gilbert R. Frith
Iowa Wastes Disposal Association	Max Levine
Iowa Wastes Disposal Association	Earle L. Waterman
Kansas Water & Sewage Works Association	Earnest Boyce
Maryland-Del. Water and Sewerage Assn.	Abel Wolman
Michigan Sewage Works Association	E. F. Eldridge
Missouri Water and Sewerage Conf.	W. Scott Johnson
Missouri Water and Sewerage Conf.	George Russell
New England Sewage Works Association	F. W. Gilcreas
New Jersey Sewage Conference	Willem Rudolfs
New York State Sewage Works Assn.	Arthur S. Bedell
New York State Sewage Works Assn.	N. L. Nussbaumer
North Carolina Sewage Works Association	W. M. Piatt
Ohio Sewage Works Conference Group	Frank Woodbury Jones
Pennsylvania Sewage Works Association	C. A. Emerson
Pennsylvania Sewage Works Association	H. E. Moses
Members-at-Large	Linn H. Enslow
Members-at-Large	W. J. Orchard

Present in person, acting as proxy:

Arizona Sewage and Water Works Assn.	George C. Anderson (for Phil J. Martin, Jr.)
California Sewage Works Association	H. W. Jewell (for Chas. G. Hyde)
Dakota Water and Sewage Works Conf.	W. H. Wisely (for Lloyd K. Clark)
Federal Sewage Research Association	A. P. Miller (for F. J. Maier)
Georgia Water and Sewage Association	Gilbert R. Frith (for Lewis Simonton)
Kansas Water & Sewage Works Assn.	Earnest Boyce (for Robert Peart)
Michigan Sewage Works Association	E. F. Eldridge (for N. G. Damoose)
New England Sewage Works Association	Gordon M. Fair (for LeRoy W. VanKleeck)
North Carolina Sewage Works Assn.	W. M. Piatt (for H. G. Baity)
Oklahoma Water and Sewage Conf.	B. A. Poole (for H. J. Darcey)
Pacific Northwest Sewage Works Assn.	Roy M. Harris (for W. P. Hughes)
Pacific Northwest Sewage Works Assn.	Carl E. Green (for J. W. Cunningham)
Rocky Mountain Sewage Works Assn.	Dana E. Kepner (for H. G. Watson)
Rocky Mountain Sewage Works Assn.	L. O. Williams (for Chas. A. Davis)
Sewage Division, Texas Sec., S.W.W.A.	F. W. Mohlman (for V. M. Ehlers)
Member-at-Large	Morris M. Cohn (for Arthur A. Clay)

The following were presented by proxy to H. E. Moses, Secretary-Treasurer:

Maryland-Del. Water and Sewerage Assn.	Harry R. Hall
New Jersey Sewage Conference	Richard C. Smith
Sewage Division, Texas Sec., S.W.W.A.	W. S. Mahlie
The Canadian Inst. on Sewage and San.	A. E. Berry
The Canadian Inst. on Sewage and San.	W. H. Riehl

The Secretary-Treasurer announced the selection by the Board of Arthur A. Clay, New York City, as Business Manager to succeed William W. Buffum, deceased. He also reported the nearly complete representation of affiliates as previously set forth.

The reading of the Minutes of the Annual Meeting of the Board held January 18, 1940, was dispensed with, they having been printed in Sewage Works Journal, March, 1940.

The matter of incorporation of the Federation was discussed, explanation being asked for and given as to what such action involved. Then upon motion, seconded and carried, the Chairman and Executive Committee were authorized to proceed with the incorporation of the

Federation as a non-profit organization, if found clearly desirable upon further investigation.

The Board's attention was directed to a motion passed at the Business Meeting of the Federation on Saturday forenoon, October 5, 1940, requesting that arrangements should be made to hold a national convention annually. It was thereupon moved and seconded that there be an Annual Convention in 1941, the time and place to be selected by the incoming Board of Control—Carried.

It was moved that the Board direct the Chairman to appoint a Convention Committee comprising three representatives from the Federation and two from the Manufacturers Association—Seconded and carried.

Mr. Emerson reported the receipt of a telegram from Harold H. Burton, Mayor of Cleveland, and one from Mark Egan, Executive Vice-President, Cleveland Convention and Visitors Bureau, Inc., inviting the Federation to hold its Annual Convention in Cleveland in 1942. He was directed to advise them that the matter will be taken under consideration.

Mr. Emerson next presented for action by the Board the Report of Committee for Expansion and Reorganization, dated September 18, 1940. He referred to the extensive work of the Committee over nearly a year in producing the report; cited the need for changes in the organization structure to enable the Federation to operate more efficiently; and mentioned the action of the Federation at its Business Meeting on Saturday forenoon, October 5, 1940, recommending to the Board of Control that it take favorable action on the proposed revisions and additions to the Constitution and By-Laws.

It was moved that the report be accepted and adopted as offered. Motion withdrawn. And it was further moved and seconded that this motion be tabled during discussion—Motion prevailed.

A long and earnest discussion followed, participated in by practically all representatives present. It seemed apparent that there was no objection to the general plan for making changes in the existing Constitution and By-Laws, which are now limiting and cumbersome due to the unforeseen phenomenal growth of the Federation; also because of the necessity of securing income to defray expenses.

The detailed discussion centered on such matters as representation on the Board, classification of members, dues prescribed and meeting dates.

It was moved that it was the sense of the meeting that Article III, Section 1 of the proposed By-Laws, be approved as submitted—Seconded and carried.

It was also moved that the question of dues be reopened and the Committee for Expansion and Reorganization again give further consideration to the matter of dues, in view of the dissent expressed at this meeting of the proposed dues, and report thereon in two weeks—Seconded and carried.

A motion was offered that Article IV, Section 3(*d*), be changed so as to provide that the Director representing a Member Association be placed on a proportional basis and that each such Director be entitled to one vote and another vote for each 100 members of his association. Motion seconded but on vote was lost.

It was moved that Article III, Section 5 of the By-Laws, be amended to provide that collection of new dues, as therein specified, be begun January, 1942 and that such action be recommended by those present—Seconded and carried.

Finally, to summarize and crystallize the will of the meeting, the following resolution was proposed and on motion, duly seconded, was adopted:

RESOLVED that it is the sense of this meeting that the Board of Control at its January 1941 Meeting should adopt and declare in effect the Revised Constitution and By-Laws proposed by the Committee on Expansion and Reorganization as proposed in their report of September 18, 1940, as subsequently modified by the Committee

AND BE IT FURTHER RESOLVED that this Board recommends to the various Member Associations favorable consideration of the Committee's Report

AND BE IT FURTHER RESOLVED that the Chair be directed to appoint a committee of five from the existing Committee on Expansion and Reorganization charged with the responsibility of presenting a report to the January Meeting with a plan and a report on ways and means to motivate and place the new Constitution in operation.

In view of the modifications suggested, the Chairman was authorized to appoint a Sub-Committee of the Committee for Expansion and Reorganization to further consider the proposed Constitution and By-Laws in the light of the discussion at the Board Meeting and to promptly report its recommendations to the said Committee, which, if approved by this Committee, will be distributed as the final draft of the proposed Revision of the Constitution and By-Laws.

The Chairman thereupon appointed this Sub-Committee comprising A. S. Bedell, G. M. Fair, F. W. Gilcreas, Max Levine and Wm. J. Orchard.

There being no further business the Board, with a rising vote of thanks to Chairman Emerson and Secretary Moses for work performed, adjourned at 10 P.M.

H. E. MOSES,
Secretary-Treasurer

Reviews and Abstracts

FOUR CONTRIBUTIONS ON POLLUTION ABATEMENT IN NEW YORK AREA

I. INTER-STATE PROBLEMS

By Seth G. Hess

Civil Engineering, 10, 270 (May, 1940)

During the past 40 years, numerous investigations have been made on the extent of pollution in the waters in and around the Metropolitan New York area. In 1932 the Tri-State Treaty Commission submitted its final report, outlining the need for establishing uniform standards of minimum treatment to be given all pollution entering the area. This led to the formation of the Interstate Sanitation Commission in 1936, with authority to bring legal action in its own name against any municipality or other entity violating classification laws which were enacted by the States of New York and New Jersey. The laws required the Commission to classify the District according to expected predominant use, designating water areas to be used for recreational purposes, shellfish culture, and the development of fish life, as Class A. Within the area of this classification, sewage should be treated: (*a*) to remove all floating solids and at least 60 per cent of the suspended solids; (*b*) to remove the Coli organisms, so that the probable number should not exceed 1 per cc. in more than 50 per cent of the samples of sewage effluent tested by the partially confirmed test, except that in waters used primarily for bathing this bacterial standard would be required only during the bathing season; and (*c*) to maintain an average dissolved oxygen content in the tidal waters of the districts surrounding the point of discharge of the sewage at not less than 50 per cent saturation. Other waters were designated as Class B, and the sewage flowing into them is required to be treated to remove all floating solids and at least 10 per cent of the suspended solids, and enough more to prevent forming sludge deposits, and to maintain a dissolved oxygen content in the waters of at least 30 per cent saturation. During the past decade, considerable progress has been made in the construction of sewage treatment works for the abatement of pollution in this area. There are now 53 treatment plants in operation, and 17 new plants or additions under construction.

It is estimated that 432,000 tons of suspended solids enter the district yearly, of which 106,700 tons are removed by treatment. In terms of the B.O.D. pollutional load, the total estimated demand before treatment is 2,044,000 lb. of oxygen per day. Of this, 252,000 lb. are being removed by treatment daily. The author presents curves for the variation in dissolved oxygen content of some of the waters in the New York area. After assembling all of the available data in this area the author believes that between $200,000,000 and $250,000,000 will be required to provide for adequate treatment within the Interstate Sanitation District. The problem of means of financing these large expenditures is now being studied.

II. PROGRESS WEST OF THE HUDSON

By C. J. Velz

Civil Engineering, 10, 349 (June, 1940)

The abatement of pollution in the area west of the Hudson River is complicated by the multitude of political units and the municipalities which are involved, the acute pollution due to industrial waste, and the proximity of the residential and industrial areas.

This part of the Interstate Sanitation District naturally is divided into a number of drainage areas which have to be considered independently. Along the Hudson River, opposite the whole length of Manhattan Island, two counties and twelve municipalities are encountered. The expense and lack of efficiency associated with the plan for each political unit to build and operate its own plant would be too great. However, the difficulties of a completely coordinated plan at times seem insurmountable. The greatest obstacle to integration is an inherent fear and lack of confidence on the part of the small units of government toward what are regarded as extravagent schemes of sewage treatment. Nothing has been done in this area as yet, and considerable education of the taxpayer will be required before anything can be accomplished.

The Raritan River Valley is a drainage area in which considerable has been accomplished through the cooperation of the municipalities, industries, the State Department of Health, and the Public Works Administration. Although an attempt was made to create a joint project, this was unsuccessful and each municipality constructed its own plant at a total cost substantially in excess of what would have been possible by joint action. It is anticipated that by 1941 the Raritan River will have been made reasonably free of pollution.

Newark Bay receives the waters from the Passaic River, the Hackensack River, and the Kills. Control over the Passaic River Valley is exercised by the Passaic Valley Sewerage Commission, which operates an extensive system of trunk sewers along the river, and a primary treatment plant located on Newark Bay, with its outlet in Upper New York Bay. This system serves a population of over a million, as well as a substantial industrial load. As a result of the efforts of this Commission, the Passaic River is now fairly clean and is in much better condition than the waters of Newark Bay into which it discharges. However, the placing of the treatment plant outlet in Upper New York Bay has aggravated conditions in that body of water and has led to many legal actions. The water discharging into the Kills comes primarily from two sources, the Elizabeth Valley Project serving a population of about 300,000, and the Rahway Valley Project serving a population of about 70,000. Some of the larger cities in this area still do not treat their sewage, but considerable progress has been made in the abatement of the gross pollution of the Kills. Industries still present a great problem along the Kills, since oil refineries, chemical and metal works discharge large quantities of waste and render the water practically devoid of dissolved oxygen. The Kills are virtually oscillating stagnant pools in which the tidal changes produce but a slight net movement toward Newark Bay. Until the problem of industrial waste is vigorously attacked, the Kills cannot be expected to improve to the extent desired by the Interstate Sanitation Commission. The Hackensack District includes a highly developed patchwork of over 50 municipalities and a large number of industries. In 1933, the State Legislature created the Hackensack River Sewerage Authority to manage pollution abatement in that drainage area. The Authority was empowered to buy and sell, construct and operate sewers and treatment works, and to issue bonds payable from revenues derived from municipalities and industry using the Authority's work. Federal money could not be obtained to assist in the construction of the contemplated project of a system of interceptors and the two large joint treatment works. Inadequate security for the bonds was the reason for the failure of the project to go through, so the Authority lost its powers in 1938. A new bill before the State Legislature seeks to modify conditions to approve financing procedure. Unless some Federal or State aid is obtained, the prospects for further immediate action are not encouraged. The larger cities and the industries have waste problems which remain practically untouched. Detailed economic studies of every feasible plan must first be carried out and presented to the people, in order to gain public confidence and the support of the municipalities and the industries within the area.

III. WESTCHESTER AND LONG ISLAND

By J. L. Barron

Civil Engineering, 10, 441 (July, 1940)

Westchester County, with a population of 600,000, extends 30 miles along the Hudson River and 11 miles along the Long Island Sound. Sewers, with treatment in some cases, were installed by the individual municipalities until 1926, when the Westchester County Sanitary Sewer Commission was established. This Commission developed a plan for constructing a system of trunk sewers to meet immediate and future needs for a period of 50 years and to concentrate sewage at a minimum number of points most favorable for treatment and discharge into the Hudson River or Long Island Sound. Over 90 miles of trunk sewers were constructed, and four treatment plants comprised of fine screens were provided at Rye, Mamaroneck, Central Yonkers, and Southern Yonkers. The cost of these fine-screening plants, plus the submarine outfalls, has approached the cost of primary treatment by settling, which would have affected a four or five times greater removal of organic matter. Chlorination is practiced to reduce the *B. coli* count. For some years most of the beaches along the Hudson River have been closed, and this has served to make the citizen conscious of the need for sewage treatment. In 1936 the State Department of Health notified all Hudson River municipalities discharging untreated sewage that adequate purification must be provided by 1940. The municipalities are following this demand and a number of treatment plants are being constructed. Progress along the Long Island Sound has been more satisfactory from the point of view of a reduction of the *B. coli* content of bathing waters. This improvement has been caused by effective chlorination at the two County plants and five local plants during each summer season. Control is now exercised over the construction of private sewage disposal systems in districts that are not sewered.

The Long Island area of Nassau and Suffolk Counties has been affected in the type of treatment given the sewage by the sandy character of the soil and its high capacity for absorption. Only where high ground water has limited absorption, or where population has reached a high density, have sewers been constructed. In Nassau County roughly only 25 per cent of the population is served by municipal systems while the remaining 75 per cent depends on private disposal. In 1934, the County secured legislative authorization for preparing a comprehensive plan of trunk sewers and treatment works to relieve the situation. The plan, as adopted, contemplates construction by a County agency with costs charged to the district served, and with lateral sewer systems constructed by municipalities or sewer districts within the trunk district. The plants proposed are of the chemical precipitation type, supplemented with some form of secondary treatment and with chlorine disinfection, and are located to discharge with short outfalls directly into tidewater. In Nassau County, there are over 300,000 people dependent upon private sewage disposal facilities, with from 80,000 to 100,000 cesspools and leaching pools. These have been constructed without particular technical knowledge and are generally faulty in design and inadequate in capacity. The County Health Department, established in 1938, has taken up this matter of private sewage disposal, and recommendations were formulated for the design and construction of cesspools, leaching pools, septic tanks, and sub-surface absorption. Rigid control by the County authorities should relieve the situation in the near future. There is considerable importance in the fact that sewage from over 350,000 people is being returned to the ground water, thus helping to conserve a resource tremendously vital to the future development of Nassau County and Long Island. When trunk sewers are established, increasing volumes of ground water will be discharged into the ocean, with the probability that a point will be reached in population growth and diversion of ground water at which a large-scale recharging of treated sewage into the sub-surface will become necessary. Artificial recharge of storm water is already being practiced in accordance with an established county policy.

IV. THE CITY ITSELF

By R. H. Gould

Civil Engineering, **10**, 508 (August, 1940)

The population of New York City comprises about 70 per cent of the total population in the area within the Interstate Sanitation District. Aside from maintaining certain standards of decency in the quality of the waters of the inner harbor, one of the main objectives of the city's program is to restore and make safe for bathing the waters available for recreational use. In general, these are the waters that have been placed in the Class A designation by the Interstate Sanitation Commission. Diagrams are presented by the author to show the effect of distance and time of flow from major sources of pollution on the natural purification that takes place in harbor waters, and indicate the fact that for adequate protective measures it is necessary to go to the source of pollution. The engineering and economic aspects of the New York City problems are very complicated. Most of the better sites for sewage treatment works have now been developed for other purposes, and the city has been forced to go to locations that in some cases are expensive to develop and are, in general, much smaller than would be desirable. These conditions have forced the city to form treatment district areas which are often somewhat smaller than would ordinarily be used if adequate sites could be obtained. Records of existing plants indicate that in a plant treating about 20 m.g.d., the personnel costs may run as high as $9.00 per m.g., whereas in large plants with flows of about 200 m.g.d., this figure will be about $5.00. Present plans indicate that the number of treatment districts will be about 16, and efforts toward consolidation will be carried to the economical limit. Investigations are being made into modification of present processes that will reduce the cost of secondary treatment and bring the power requirements for this treatment within the amount that can be secured from the sewage itself through the use of gas engines and other power recovery devices. The need for use of sewage sludge as fertilizer is also great, considering the many square miles of parks and parkways in the city. As soon as it is economically feasible, the city hopes to recover from the sewage sufficient fertilizer to meet the requirements of these parks.

The problem of financing the cost of construction of sewage treatment plants is one of the major problems confronting the city at the present time. Like many smaller cities, New York is close to the limit of its debt-incurring powers for capital works and its annual operating budget is close to the limit that can be legally raised by taxation. The sewage disposal program, while in itself not excessively costly for a city of its size, must compete with other demands for the relatively meager funds available. Up to the present, New York City has spent about $41,000,000 for the construction of new treatment works. Of that amount, approximately $11,800,000 will be returned as grants from the Federal government. It is estimated that $148,000,000 additional will be required in order to furnish treatment for all of the sewage of the city. Studies indicate that the annual charges for debt service and operation for the works under the program will increase gradually to a peak of from 14 to 15 million dollars per year. This is only a little over 2 per cent of the city's annual expenditures and is certainly not excessive in view of the importance of sewage disposal in the general municipal picture. The outstanding necessity at the present moment is for the establishment of a definite and assured annual income, from sources other than real estate and taxes, that will permit the prompt and complete solution of the sewage disposal problem. The importance of this problem dictates that it should be divorced from the complexities of the tax levy and capital outlay budgets, with their constitutional limitation as to the amount of expenditure, and the competition of projects that may have a more immediate popular appeal, such as bridges, hospitals, and schools. The urgency and importance of restoring the condition of the waters around New York City is ample justification for placing the program on a self-sustaining status based upon services rendered.

Rolf Eliassen

THE BARSTON WORKS OF THE BIRMINGHAM TAME AND REA DISTRICT DRAINAGE BOARD

By C. H. Hewitt

The Surveyor, 98, 163–165 (Oct. 4, 1940)

The Barston Works serves a small portion of the area included in the Birmingham Tame and Rea Drainage District, with a tributary population of 21,000 and an average dry weather sewage flow of 0.75 m.g.d. The works may be considered typical in size and design of many throughout England.

The plant was originally constructed in 1910 and was revised and enlarged in 1933–35. Treatment is furnished by detritus tanks, plain sedimentation tanks, storm water tanks, trickling filters with rotary distributors, humus tanks, grass filters, separate sludge digestion tanks, and sludge drying area. The effluent is received by the Blythe River, a rural stream, and constitutes the sole discharge therein in dry weather.

The trickling filters are 6 ft. deep and carry, in dry weather, a loading of approximately 100 gal. per cu. yd. per day. Four new beds have media of 1 in. to 1½ in. crushed gravel. Of the four older beds, one remains as originally constructed with a 2 ft. surface layer of ¼ in. to ½ in. slag, with middle and bottom layers of 1 in. and 2½ in. crushed granite; the remaining three original beds have had the top slag layer replaced with 1 in. to 1½ in. crushed gravel.

Determinations have been made of the time of contact in the unaltered original bed in comparison with one of the new beds. At a dosage of 100 gal. per cu. yd. per day, the time of contact was 2.42 hr. for the unaltered bed and 1.58 hr. for the bed containing 1 in. to 1½ in. gravel. The unaltered bed does not give an appreciably better effluent at this loading and is unable to take flows much in excess of this quantity because of resultant pooling. The newer beds, on the other hand will take higher flows without pooling and without appreciable deterioration of effluent.

Measurements have been made of the quantity of dry solid material contained on the media in the Barston bacteria beds. In 1937, in one of the beds containing 1 in. to 1½ in. gravel, 5.9 lb. of dry solid material, containing 73.9 per cent organic matter, 14.2 per cent silica, and 6.1 per cent Fe_2O_3, was found per cu. yd. of gravel. In the unaltered bed, containing finer material, the solids are considerably greater in amount and of lower organic content.

Results of treatment are partially given in the accompanying table. The figures tabulated are 1939 averages except the raw sewage and sedimentation tanks effluent suspended solids figures which represent the range of annual averages.

Results of Analyses—P.P.M.

	* Suspended Solids	Oxygen Absorbed 4 Hrs. @ 80° F.	B.O.D.* 3 Days @ 80° F.
Raw Sewage	163 to 240	59	236
Sedimentation Tank Effluent	31 to 61	26	108
Trickling Filter Effluent	54	7.9	9
Humus Tank Effluent	23		
Grass Plat Effluent	11		

* "Suspended solids" as given, were determined by filtration and weighing of settleable solids.

Primary and humus tank sludges are pumped at fortnightly intervals to two-stage digesters. Each such charge of approximately 5.25 per cent solids, amounts to approximately 25 per cent of the primary digestion tanks capacity. Dry raw sludge solids, in 1939, amounted to 813,000 lb. of 68.2 per cent organic matter. Digested sludge stays on the drying beds about 6 months and is removed at approximately 65 per cent moisture.

Vernon G. MacKenzie

SHANGHAI PUBLIC WORKS COMMISSIONER'S ANNUAL REPORT (SEWAGE TREATMENT AND DISPOSAL SECTION)

The Surveyor, **98**, 137 (Sept. 13, 1940)

At the Western Works, closed under " force majeure " in October, 1937, operation was resumed by permission in March, 1939. New activated sludge had been developed by May 10, after which the plant was in full operation and handled 644.98 m.g. in the remainder of the year. It was found that the sewage flow and strength had increased in such amount as to more than double the 1936 load, thus substantially overloading the plant. Routine operation was interfered with by trying and sometimes disastrous circumstances, such as difficulties in obtaining passes for the operating staff and power failures due to theft of power company cable. Sludge disposal suffered from the impossibility of obtaining suitable sand.

Operation at the Eastern Works, discontinued in August, 1937, was resumed in April, 1939, after which 471.41 m.g. were treated. The abnormal local situation reacted unfavorably on the treatment obtained. Sludge disposal operations were embarrassed by the absence of the local farming community, which normally is depended upon to use this material as fertilizer.

While the sewage treatment plants were out of operation, stream pollution surveys of the local waterways were made. The evidence of these indicates domestic sewage is a comparatively small factor in the obviously unsatisfactory conditions, trade waste and drainage appearing to be the principal sources of pollution.

V. G. MacKenzie

FIRST YEAR'S OPERATION OF RICHMOND-SUNSET SEWAGE TREATMENT PLANT

By B. Benas

Civil Engineering, **10**, 641 (October, 1940)

The main sewage treatment plant of the City of San Francisco is located in Golden Gate Park, and treats the sewage from the westerly slope of the city, comprising the Baker's Beach, West Richmond, and Sunset districts. The plant was designed (1) for removing large floating material, grit, grease, and suspended solids; (2) for the addition of chlorine for odor control and bacterial disinfection during the time the beaches are in use; (3) for digestion of the screenings, grease, scum, and sludge; and (4) for elutriation and filtration of the digested sludge. The author presents flow diagrams of the layout of the sewage treatment plant and the various processes. The plant went into service in April, 1939. The records to date show that the average flow varies from 6.5 to 9 m.g.d., the lower flow occurring during the summer months. During storms, the Sunset flow is by-passed to prevent large quantities of sand from being carried into the plant, as the Sunset area has a large number of dunes of very fine sand. When the Richmond flow reaches 18 m.g.d., it is by-passed directly to the discharge sewer.

A summary of the operation of the various units of the plant is given. The bar screens have removed approximately 3 cu. ft. of screenings per million gallons of sewage and no difficulty has been experienced in the handling of the screenings by buggies or the shredding of screenings in the sludge control house. The sand brought to the plant by the combined sewers is very fine, a large portion being between .017 and .010 mm. in size. This sand would not deposit in a normal grit chamber with a velocity of 1 ft. per sec., so it was necessary to design a grit tank that would allow lower velocities without deposition of undue quantities of organic material. Imhoff type aerated tanks have been provided, having a holding time of ten minutes at average flow. In these tanks, the washed grit is deposited at the bottom and grease is collected in quiescent zones at the surface. It was found that velocities of approximately 4.5 ft. per sec. in the discharge line were too low for the sand, and it was necessary to go up to velocities of 8 ft. per sec.

to prevent deposition. From ½ to 3 cu. yds. per day of washed sand were removed in the classifier which follows the aeration tank. It was found that 0.05 cu. ft. of air per gallon of sewage was satisfactory for the maximum amount of sand removal with a minimum of organic material. This rate was also satisfactory for grease removal, approximately 1,300 gal. per day of grease liquid being obtained. Flocculation for 30 minutes is followed by sedimentation for 1.5 hours at average flow. The tests indicate that the over-all removal of suspended solids varies from 70 to 80 per cent during normal operating conditions over the past year for a sewage with an average strength of 350 p.p.m. suspended solids. The suspended solids removal has been found to be a function of the rate of withdrawal of sludge from the sedimentation tank. If sludge is allowed to accumulate in these tanks, it will adversely affect settling. By continuously withdrawing sludge, it is possible to obtain an effluent of not over 50 p.p.m. of suspended solids. The scum is removed from the sedimentation tanks by water sprays, using treated effluent to carry the scum to the inlet end of the tank. Chlorine is added to the sewage before it reaches the plant for odor control, and to the effluent for bacterial disinfection. Approximately 30 lb. per million gallons is required for pre-chlorination, while for post-chlorination the rate varies from 60 to 120 lb. per million gallons.

Sludge from the sedimentation tanks is withdrawn to sludge thickening tanks into which are also added ground screenings and grease. It has been found that a detention time of at least 1.5 hours was required for adequate thickening to obtain a sludge with 95 per cent moisture. Sludge is digested in a single tank, although it was originally intended to have this tank act as the first unit of a two-stage digestion system. The pH of the digester has been maintained between 6.9 and 7.1 and the temperature carried at 90° F. The sludge at the bottom of the digester is 96.5 per cent moisture and the supernatant 99.6 per cent moisture. The building of a second unit should prove the character of the supernatant. The reduction of volatile matter has ranged between 50 and 60 per cent. A gas generator varies from 90,000 to 160,000 cu. ft. per day and average about 1.0 cu. ft. per capita of connected population. Elutriation of the digested sludge and supernatant has been found beneficial. Four per cent ferric chloride is necessary to filter the elutriated sludge having 96 per cent moisture content. Filtering rates of 6 to 6.5 lb. of dry solids per sq. ft. of filter area per hour on a filter of 200 sq. ft. net area are being obtained. A constant laboratory check is being maintained on plant operation.

ROLF ELIASSEN

OXIDATION OF LACTOSE BY ACTIVATED SLUDGE

BY S. H. JENKINS AND R. WILKINSON

J. Soc. Chem. Ind. Trans., 59, 125–128 (1940), (No. 6)

The experiments were conducted in 45 liter capacity tanks. The tanks were dosed with different quantities of lactose supplemented with dihydrogen phosphate and ammonium carbonate once a day and aerated vigorously.

Lactose was removed at a high rate during the first hour. Small amounts of lactic acid were found during the early part of aeration which disappeared after 24 hours. The pH value dropped to 4–5 in the early part of aeration when 2190 p.p.m. of lactose was used. Soluble phosphate was absent one hour after the addition of lactose. The increase in weight of sludge during 35 day dosing period varied from 39 to 44 per cent of weight of lactose added, depending on the amount of lactose fed.

After a few weeks the sludge treated with lactose became extremely dense and occurred in short thick well-defined clumps dark brown or almost black in color. It did not bulk as often happens when activated sludge is aerated with solutions of carbohydrates. A fungus identified as *Pullularia pullulans* was the dominant organism. Percentage of fat and nitrogen in the sludge decreased when the sludge was fed with lactose. When lactose and ammonium carbonate were added to activated sludge on C/N ratio of 150:1 and 10:1 for a period of 28 days the increase in the weight of sludge was approximately the same except during the last seven days of the experiment, when a decrease in the

amount of reserve nitrogen in the sludge with the lower C/N ratio restricted the growth of the sludge.

The rate of disappearance of lactose was influenced by the C/N ratio. The fat content of the sludge fed with a C/N ratio of 150:1 increased from 0.6 to 5.8 per cent and the nitrogen content decreased from 4.68 to 1.14 per cent. In the tank supplied with nutrients in the C/N ratio of 10:1 the percentage fat in the sludge remained low and the total nitrogen increased from 4.68 to 5.2–5.3 per cent.

H. HEUKELEKIAN

THE NITROGEN CYCLE IN BIOLOGICAL SYSTEMS

I. SOME CONDITIONS AFFECTING THE DISTRIBUTION OF NITROGENOUS COMPOUNDS DURING TREATMENT OF SEWAGE BY THE ACTIVATED SLUDGE PROCESS

BY ALEXANDER S. CORBET AND WALTER R. WOOLDRIDGE

Biochemical Journal, **34**, 1015–1025 (1940)

Laboratory experiments were conducted to determine the distribution of nitrogenous compounds in the activated sludge process. At different periods of aeration of activated sludge and sewage mixtures samples of the sludge were tested for adsorbed ammonia-N by exchanging the adsorbed ammonia with KCl in an acid solution. The results showed that the amount of ammonia nitrogen adsorbed on the sludge was greatest shortly after addition of fresh sewage and decreased as the treatment proceeded; the amount adsorbed at any time was small.

In activated sludge-sewage mixtures which did not nitrify on aeration, the diminution of ammonia nitrogen could be accounted for by the increase of the nitrogen content of the sludge. When potassium nitrite or nitrate were added to such a sludge there was a rapid diminution during aeration of the concentration of oxidized nitrogen and only a small portion of this diminution could be accounted for by an increase in organic nitrogen. The added nitrite was not converted into nitrate but nitrite was always detected during aeration of mixtures to which nitrate had been added. In the experiments with sewage alone and with added ammonia nitrogen the total nitrogen in the mixtures remained constant during aeration of three days. In the experiments in which nitrite or nitrate was added the total nitrogen decreased rapidly by an amount approximately equivalent to the decrease in the content of nitrite or nitrate. There was no loss of ammonia nitrogen from aerating mixtures unless large quantities were added and aerated for long periods (14 days). The loss of nitrogen when nitrite or nitrate were added was in the form of nitrogen gas and not in the form ammonia nitrogen. The amount of nitrogen thus lost increased as the concentration of added nitrate or nitrite increased. No indication of the formation of hyponitrous acid or any other intermediate compound was obtained.

With nitrifying sludges a large proportion of the ammonia nitrogen of the sewage or the added ammonium salt was converted to nitrate with intermediate formation of nitrite and hyponitrite. When potassium nitrite was added to nitrifying sludge and sewage mixtures, the concentration of nitrite remained nearly constant during aeration until the whole of ammonia nitrogen had disappeared and had been converted into organic nitrogen in the sludge; the nitrite was then oxidized to nitrate.

Some experiments on changing the carbon-nitrogen ratio of activated sludge by daily feeding with glucose showed that the ratio in the sludge itself was not affected by widening of the ratio of the feed mixture. When glucose was fed nitrification was inhibited because, in the presence of excess available carbonaceous material, the ammonia nitrogen was utilized in the formation of insoluble organic nitrogenous compounds in the sludge.

Simultaneous determinations of B.O.D., ammonia, nitrite, nitrate and bacterial numbers in activated sludge-sewage mixtures during aeration showed that an early and rapid oxygen uptake was correlated, whether or not nitrate was formed, with a rapid decrease of ammonia nitrogen and an increase in bacterial numbers.

The authors conclude that the failure of certain sludges to nitrify is not due to the inhibiting influence of ammonium ions on the nitrifying flora. However, it is shown that with increasing initial ammonia nitrogen concentration its conversion into organic nitrogen is retarded.

Initial NH_3-N in Liquid, p.p.m.	8	32	57	107	157	207	256
Per cent of NH_3-N in liquid phase converted to org. form after 14 days aeration	100	85.4	51.4	23.9	15.2	9.3	6.2
Increase in organic N in mixture	8.0	28.0	29.6	25.6	24.0	19.2	16.0

The excess ammoniacal nitrogen not converted into organic form remained unaltered in the liquid and was not oxidized to nitrate or nitrite. Nitrifying organisms were present in sludges that failed to nitrify. The failure of nitrification to take place with certain sludges is not explained.

H. HEUKELEKIAN

THE NITROGEN CYCLE IN BIOLOGICAL SYSTEMS

II. CHANGES IN MIXTURES OF SEWAGE AND ACTIVATED SLUDGE ENTAILING THE LIBERATION OF NITROGEN

BY WALTER R. WOOLDRIDGE AND ALEXANDER S. CORBET

Biochemical Journal, 34, 1026–1035 (1940)

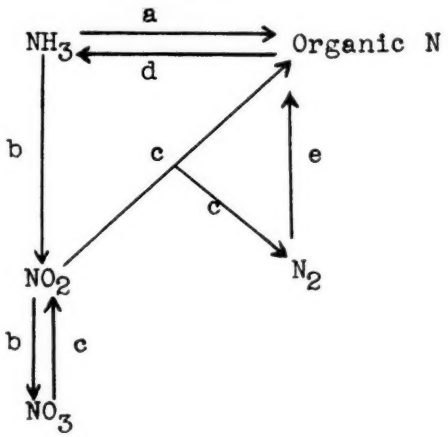
This paper deals with the loss of nitrogen observed in the previous study with non-nitrifying sludges to which had been added an oxidized form of nitrogen. When sterilized mixtures of activated sludge and sewage were inoculated with pure cultures of different organisms such as *Staphylococcus albus, Chromobacterium prodigiosum, Pseudomonas pyocanea* and *Torula nitriverters* and incubated for two weeks there was often a significant loss of nitrogen. The loss of nitrogen from non-sterile mixtures of sewage and activated sludge can be largely prevented by the addition of glucose and pyruvic acid whereas the loss may be increased by the addition of nitrate or glycine. These compounds acted in a similar way when added to sterilized activated sludge-sewage mixtures inoculated with different organisms.

A pure culture sludge was developed by aerating sterilized sewage and sludge inoculated with *Chromobacterium prodigiosum*. Purification of sterilized sewage brought about by such a pure culture sludge was studied. B.O.D. reduction within 4 hours aeration period was negligible. As the organism was not a nitrifier, no nitrification occurred but a part of the ammoniacal nitrogen was utilized for synthetic requirements. The addition of ammonia nitrogen to such a pure culture sludge resulted in a greater production of protein and a loss of some ammonia in the air stream.

Rising of activated sludge with both nitrifying and non-nitrifying sludges can occur. With nitrifying sludge rising can take place when there is no denitrification but a slow accumulation of nitrite from the oxidation of ammonia. Occasionally a non-nitrifying sludge may give rise to nitrite followed by an accumulation of this compound and rising of the sludge. Rising can be initiated or aggravated with a non-nitrifying mixture by the addition of nitrite or nitrate and can be inhibited by the addition of assimilable carbonaceous materials such as glucose or starch. The results suggest that rising is dependent upon nitrite formation being in progress while some organic matter remains in the sewage for it appears that nitrogen liberation occurs principally during the utilization of nitrite for protein synthesis.

Since the results in this investigation showed that the nitrogen loss in the aeration of sewage and sludge mixtures was usually slight and that such loss was invariably associated with the presence of nitrite, the extent of chemical decomposition of nitrite as a cause of the loss of nitrogen was investigated. Under sterile conditions continuous aeration of activated sludge sewage mixtures containing added nitrite and ammonia nitrogen did not result in a loss of nitrite. The evidence cited supports the belief that the loss of nitrogen was not due to chemical reactions involving nitrite. The nitrogen loss involving the reaction between amino acids and nitrite were also ruled out since determinations during aeration experiments of sewage and sludge mixtures failed to detect amino acids in any significant amounts. It was concluded, therefore, that the loss of nitrogen under aerobic conditions was primarily due to the action of micro-organisms or their enzymes upon nitrate. It is contended that in the absence of ammonia-N, the conversion of readily available organic matter into more complex forms containing N can be effected at the expense of any nitrite or nitrate present. Such "organization" of nitrite or nitrate nitrogen occurs concurrently with losses of nitrogen.

The nitrogen transformations in activated sludge are represented by the following diagram:



The individual reactions in the diagram are encouraged by the following chemical conditions:

(*a*) The presence of ammonia and assimilable carbon compounds.
(*b*) Ammonia present but little or no assimilable carbon compounds.
(*c*) Assimilable carbon compounds present together with nitrite and/or nitrate as the most readily available source of N.
(*d*) Autolytic changes arising from absence of nutrient materials.
(*e*) Fixation of nitrogen in the presence of assimilable N-free organic compounds and no readily available source of N other than free gas.

Activated sludge normally contains all requisite enzymes for the nitrogen changes presented above but the actual course depends upon the chemical nature of the liquid phase.

H. Heukelekian

THE EFFECT OF OXYGEN TENSION ON THE OXYGEN UPTAKE OF LAKE BACTERIA

By Claude E. Zobell and Janice Stadler

Jour. Bact., 39, 307–322 (1940)

Lake water was adjusted to different dissolved oxygen concentrations ranging from 0.74 to 7.41 p.p.m. by passing nitrogen gas through it, incubated for a period of 10 days and at intervals the oxygen uptake was determined. Leaving out the lowest dissolved oxygen concentration which soon was practically depleted and considering only the range from 1.69 to 7.41 there was some slight increase in oxygen uptake with increasing initial D.O. concentrations. When the results are expressed on the basis of oxygen uptake per cell per hour, the different initial dissolved oxygen concentrations showed little differences. However the rate of oxygen uptake per cell was highest during the first day irrespective of the initial dissolved oxygen and decreased gradually up to the fourth day. The decrease in the respiratory rate is attributed to the decrease in available organic matter. The respiratory rate of resting cells studied over short periods of time in lake water was independent of the oxygen tension of the water. The respiration rate of resting cells was similarly unaffected at dissolved oxygen concentrations varying from 8.5 to 34.5 p.p.m.

Thus the conclusion is reached that rate of respiration of lake bacteria in growing and resting state is independent of the oxygen tension of the water. However bacterial multiplication is affected by the dissolved oxygen content. The author states that under certain conditions such as in concentrated nutrient solutions or substrates rich in particulate matter, oxygen may become a limiting factor while there is still some oxygen present. All of the oxygen is depleted in the immediate vicinity of the respiring cell especially when the latter occur in clumps.

In such localized areas oxygen may be consumed faster than it can be replaced by diffusion. Under such conditions increasing the oxygen tension increases the oxygen gradient and may provide for the replenishment of oxygen.

H. Heukelekian

INDIANAPOLIS SEWAGE PLANT NEEDS ENLARGEMENT

Engineering News-Record, 125, 102 (September 12, 1940)

The 1939 report of the Board of Public Works and Sanitation of the City of Indianapolis states that consideration must be given to the expansion of the sewage treatment plant at Indianapolis within the next two years, if the city continues to grow in population and industry. There is not sufficient plant capacity to treat all of the sewage by the activated sludge process, but in spite of this, the White River was maintained in reasonable condition throughout the year. Although the quantity treated was less in 1939 than in 1938, the sewage was stronger and the longer detention periods in the aerators required a greater amount of air. Digested sludge disposed of in 1939 amounted to 35,050 cu. yd., or 35 per cent more than the previous high record. Practically all of this went as fertilizer to market gardeners. The cost of operation of the plant was $8.81 per million gallons of sewage treated, of which 78¢ was for grit chamber and incinerators, $3.07 for clarification and pumping, $4.26 for secondary treatment, and $0.31 for sludge disposal. Garbage reduction of 29,348 tons was 7 per cent higher than in 1938, which was 12 per cent higher than in 1937, indicating a gradual yearly increase. The cost of operation for the garbage reduction plant averaged $3.55 per ton. This plant alone sold 2,657 tons of fertilizer, 1,027 tons of feed, and 832 tons of grease.

Rolf Eliassen

REFUSE AND SEWAGE PLANT COMBINED FOR PROFIT

By G. O. Consoer and D. W. Townsend

Engineering News-Record, **125**, 221 (August 15, 1940)

Rock Island, Illinois, has installed a modern sewerage system, with new storm water and intercepting sewers, pumping equipment, a dual sewage and garbage treatment plant, with incinerators for both municipal refuse and sewage sludge, designed to serve a population of 50,000 in 1960. About 1,100 acres of the city are at such low elevation as to require pumping of storm water during high water stages of the Mississippi River, the maximum storm discharge being estimated at 400 c.f.s. Five gas engine driven pumps and two electric (standby) pumps are to be installed for the intermittent storm water service. These pumps will be installed in the sewage treatment plant. Two major gravity relief sewers were also installed for the purpose of relieving the existing sewers and eliminating unnecessary pumping of water from areas able to discharge to the river by gravity.

The pumping station and sewage treatment plant are located in the low-level area. Flooding is prevented by having the top of tanks and other structures above the highest flood record of the Mississippi River. This necessitates the pumping of dry-weather flow at all times. Sewage treatment consists of primary sedimentation followed by magnetite filters for the effluent from the settling tanks. It is estimated that on an average sewage flow of 7 m.g.d., it will remove from the raw sewage approximately 65 to 70 per cent of the suspended solids and 40 to 45 per cent of B.O.D. The city's sewage is of moderate strength, and the B.O.D. amounts to 0.21 lb. per capita. The settling tanks are designed on the basis of a detention period of 1.5 hours at the average flow. The magnetite filter is designed to operate at rates of 1, 2, or 3 gallons per sq. ft. per minute for minimum, average, and maximum sewage flows, respectively. It has a 3-inch layer of magnetite sand of such size that 95 per cent will be retained on a No. 20 sieve, and 100 per cent will pass through a No. 10 sieve. Two sludge digesters are included, with a design capacity of 3 cu. ft./capita, based on 50,000 future population.

Garbage disposal will also be included in the plant facilities. Provision has been made for garbage grinding in two grinders of the swing-hammer type, each rated at four tons of green garbage per hour in reducing the material to pass a ½-inch screen. The ground garbage may be mixed with the incoming sewage, added to the settled sludge and pumped with it to the digesters, or mixed with the digested sludge entering the incinerator. Filtered digested sludge and ground garbage from a population of 50,000 may approximate 18 tons of dry solids daily, and is estimated to contain 10,000 B.T.U. per pound. Mixed municipal refuse will amount to approximately 30 tons per day and will be burned in a trash incinerator.

Special attention has been given to the production, use, and storage of sludge gas. The gas will ordinarily be used for all pumping and for firing the sludge and refuse incinerators. Because of a large peak demand for gas for pumping during storms, two gas-holders of 50,000 cu. ft. capacity and 50 lb. pressure are provided to insure reserve supply. A small gas engine generating unit will furnish current for lighting and for miscellaneous machines. Buildings and sludge digesters will be heated either from heat exchangers on the exhaust line of the engines or by gas fired heaters. It is expected that the plant will be self sufficient for heat and power requirements.

Rolf Eliassen

DUAL UNITS SOLVE RESORT SEWAGE PROBLEM

By A. Dale Swisher

Engineering News-Record, **125**, 405 (September 26, 1940)

In the Iowa Great Lakes region, near Milford, Iowa, a sewage treatment plant has been built with dual treatment units for handling large and small flows from a resort area

where the population varies from 30,000 in summer to only 3,000 during the major part of the year. The plant is of the activated sludge type, with the smaller of two units designed for a flow of 750,000 g.p.d., while the two units together are capable of treating a 1,940,000 g.p.d. peak flow. Control of lake pollution in this popular vacation area was recognized as an obligation of the entire state, with the result that the Iowa legislature appropriated funds to pay in part for sewers and the treatment plant. The project included trunk and lateral sewers, and four pumping stations, together with the treatment plant.

The unusual features of this plant are the provisions for treating seasonal flows, the use of the "Currie Clareater," and the normal method of heating sludge. Two sludge digesters are provided, one 30 ft. diameter tank for primary digestion and a 38 ft. diameter tank for settling and storage of the digested sludge. The primary digester is heated and has a ten-day capacity under maximum load, while the secondary is unheated and provides 4 cu. ft. per capita storage, based on the winter population of 3,000. The sludge is heated by passing it through a cylindrical shell which surrounds a pipe coil containing circulating hot water. The sludge may be recirculated at a rate of 500 g.p.m. No heating coils are located inside the digestion tank. It is expected that the sludge can be maintained at a high enough temperature to complete digestion within a month with this novel heating arrangement.

ROLF ELIASSEN

NEW ENGLAND'S NEWEST SEWAGE WORKS

BY E. J. CLEARY

Engineering News-Record, 125, 396 (September 26, 1940)

Springfield, Mass., has met its obligation toward pollution abatement in the Connecticut River by the construction of two sewage treatment plants. Treatment of the sewage was relatively simple, requiring only grit removal and sedimentation. The fact that sludge handling and disposal is the biggest problem in sewage treatment was emphasized here with facilities for sludge processing dominating the plant in size and cost. The smaller plant has a capacity of 3 m.g.d. and employs primary treatment, sludge digestion, and sludge drying on glass-inclosed sand beds. The main treatment plant is located on the West side of the Connecticut River and has a capacity of 30 m.g.d.

The larger plant is surrounded by an earthdike 3 ft. higher than previous record flood levels. The dike, which rises 16 ft. above the meadows, incloses an area 1,100 ft. long and 800 ft. wide. A subsurface drainage system has been installed to take care of river infiltration or heavy rainfall. Three pumps, operating against a head of 37 ft., discharge water from this drainage system directly to the river. Sludge is collected in the primary settling tanks and pumped to four digestion tanks. Gas is stored in a 36 ft. diameter spherical pressure tank having a capacity of 25,000 cu. ft. at a pressure of 30 lb. per sq. in. Gas will be used for heating sludge, to provide heat for all plant structures, and for auxiliary incinerator fuel. The digested sludge is elutriated in a two-stage countercurrent washing system to remove soluble decomposition products. This should result in operating economy through a reduction of more than 50 per cent in the required amount of iron salts for sludge conditioning and the complete elimination of lime. Two mixing and two settling tanks are used in the elutriation process. Water for washing is obtained from wells and is used to wash the sludge in the second stage tank. The overflow from the second tank goes to the first to wash the sludge from the digester. The overflow from the first tank, in turn, goes to the plant influent to be treated with the raw sewage. Elutriated sludge is filtered on vacuum filters after which it passes through the incinerator. This incinerator is of the flash-drying type, equipped with dryer, furnace, dust collector, and odor elimination devices. It has a capacity of 10.5 tons dry weight of digested solids per day, or 32.4 tons per day of sludge filter cake containing up to 73.5 per cent moisture.

ROLF ELIASSEN

SEATTLE'S HENDERSON STREET SEWAGE TREATMENT PLANT

By M. O. Sylliaasen

Civil Engineering, **10**, 575 (September, 1940)

The first modern sewage treatment plant in the City of Seattle has recently been completed and placed in operation. Seattle lies between Lake Washington and Puget Sound. Combined storm and sanitary sewers are in use, and during period of maximum runoff a portion of the flow in the trunk sewers is allowed to overflow into various lakes and waterways at convenient locations. Approximately the north half of the city is served by the North Trunk Sewer, which has an outfall at an excellent location on Puget Sound, where the currents are offshore regardless of wind or tide. Treatment of this sewage may never be necessary, inasmuch as little or no offense is created. The remainder of the city is served by many small sewers, also with outfalls along the shore of Puget Sound and in the Duwamish River Waterway, which is tributary to the Sound. The Henderson Street Sewage Treatment Plant handles the bulk of the flow which previously reached the Duwamish Waterway untreated. This plant is designed to serve a population of 32,000 and a flow of 8 m.g.d., and is intended merely to eliminate visible nuisance and odor and to protect commercial and game fish. The Duwamish River is not used for drinking, bathing, or industrial purposes, and it was determined that primary treatment would be sufficient. A complete flow diagram is presented by the author to show the pumping plant, Parshall flume, detritor, comminutors, clarifiers, two-stage digestion system, and glass covered drying beds. Provision has been made for the installation of two flocculators to bring about raw sewage flocculation in the future. The site was developed by hydraulic fill overlying uncertain river-bottom mud, with a ground-water level as high as El. + 2.0, or just 6 ft. below the clarifier weirs. All structures are of reinforced concrete, and all are supported on timber piling except the pump chamber. The total cost of the plant, including engineering charges, was $323,000. Operating data is not available at the present time, because the load is far below the design flow during the extension of the system of intercepting sewers.

Rolf Eliassen

BOOK REVIEW

Sewage Treatment. By Karl Imhoff and Gordon M. Fair. John Wiley & Sons, Inc. 1940. Pp. 370.

This is a joint effort of the authors to present briefly and simply the considerations and calculations which enter into the design and operation of modern sewage treatment plants, the disposal of industrial wastes, and the disposal of effluents in streams. The table of contents is as follows:

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Miscellaneous; General Tables, Etc.	8	"
Index	17	"

The book is an interesting attempt to give a world-wide viewpoint on procedure and practice, in a concise form. It would seem wiser not to have interspersed German or English practice with that current in the United States, frequently without warning, but to have confined the book to the United States. For some time the reviewer has desired to see really authoritative and separate books on practice in the British Empire and in Germany or Europe. Further, the book is almost too concise, and thereby fails to present enough detail to warn the student of the pitfalls ahead, or to discuss variations from the somewhat arbitrary dicta made necessary by the brevity of the text. There are occasional mathematical short-cuts (p. 63) that may be confusing, rather than helpful.

The tabular data outlined as common values should be qualified, in each case, or by the preface, as restricted to separate systems, and not of service on combined sewers. The data will actually vary widely in various communities. Peak loads, in weeks and months, should be commented on, and the effect of ground water infiltration on computed or actual flows. Maybe water-tight sewers are built in Europe, but they are not very common in the United States. Storm water treatment is so uncommon in North America that only two examples come to mind, North Toronto and Columbus, Ohio. Yet the authors discuss it as though a common procedure.

The book is of value for readers experienced enough to recognize the differences in German, British and American practice, and for those who wish to supplement a general knowledge of sewage disposal and stream pollution by special studies of design or, for instance, oxygen relations in stream studies. The average engineering reader may have difficulty in obtaining a well-balanced concept of sewage practice from this book. It would be more valuable if it were twice as long, with more explanatory matter.

The experienced sanitary engineer, familiar with the care and discrimination of the authors in the selection of design and research data, will derive helpful stimulation and enjoyment from a careful study of this book, including the design problems and oxygen balance computations which provide excellent mental discipline. In short it is a "different" book.

It is pleasant to welcome this outstanding contribution from two leaders in sewage progress. The low price of three dollars will appeal to those graduate students and sewage works operators who are seeking food for thought and cannot afford to buy every book in the field of sewage disposal.

LANGDON PEARSE